US009386380B2

(12) **United States Patent**
Chu et al.

(10) **Patent No.: US 9,386,380 B2**
(45) **Date of Patent: Jul. 5, 2016**

(54) **METHOD FOR THE INTEGRATION OF A MICROELECTROMECHANICAL SYSTEMS (MEMS) MICROPHONE DEVICE WITH A COMPLEMENTARY METAL-OXIDE-SEMICONDUCTOR (CMOS) DEVICE**

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(72) Inventors: **Chia-Hua Chu**, Zhubei (TW); **Chun-Wen Cheng**, Zhubei (TW)

(73) Assignee: **Taiwan Semiconductor Manufacturing Co., Ltd.**, Hsin-Chu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/524,074**

(22) Filed: **Oct. 27, 2014**

(65) **Prior Publication Data**

US 2016/0119722 A1 Apr. 28, 2016

(51) **Int. Cl.**
H04R 19/00 (2006.01)
H04R 19/04 (2006.01)
H04R 31/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H04R 19/005*** (2013.01); ***H04R 19/04*** (2013.01); ***H04R 31/006*** (2013.01); *H04R 2201/003* (2013.01)

(58) **Field of Classification Search**
CPC ... H01L 41/00; H01L 27/20; B81B 2207/094; B81B 2201/0257; B81B 3/0051; H04R 19/005; H04R 19/04; H04R 2201/003
See application file for complete search history.

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Gregor Feiertag, et al., "Packaging of MEMS microphones", Proc. SPIE 7362, Smart Sensors, Actuators, and MEMS IV, vol. 7362, p. 73620D-1-73620D-8, May 18, 2009.

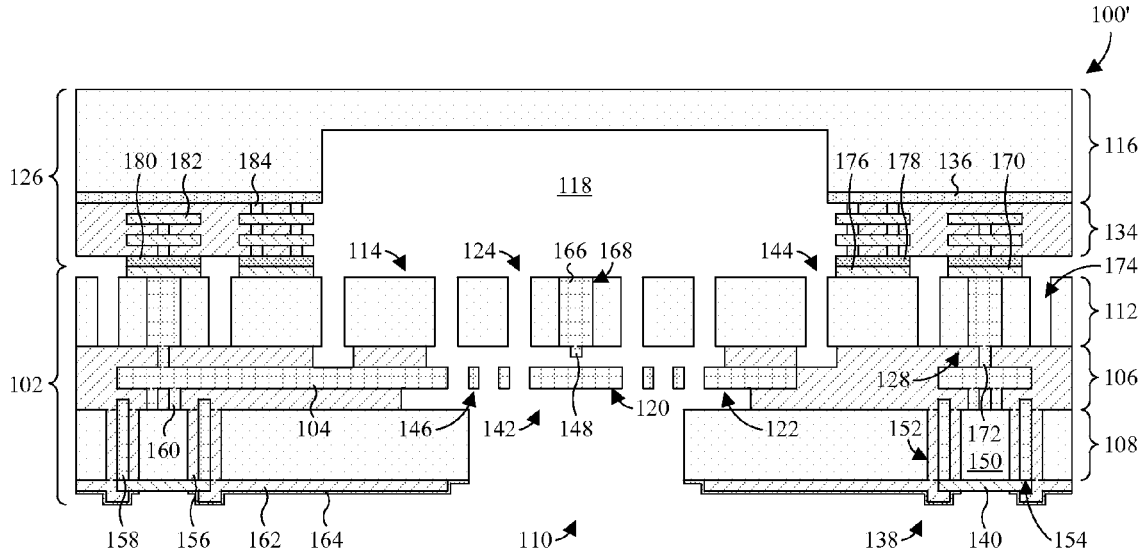
* cited by examiner

Primary Examiner — Armando Rodriguez
(74) *Attorney, Agent, or Firm* — Eschweiler & Associates, LLC

(57) **ABSTRACT**

A microelectromechanical systems (MEMS) package includes a MEMS device and an integrated circuit (IC) device connected by a through silicon via (TSV). A conductive MEMS structure is arranged in a dielectric layer and includes a membrane region extending across a first volume arranged in the dielectric layer. A first substrate is bonded to a second substrate through the dielectric layer, where the MEMS device includes the second substrate. The TSV extends through the second substrate to electrically couple the MEMS device to the IC device. A third substrate is bonded to the second substrate to define a second volume between the second substrate and the third substrate, where the IC device includes the first or third substrate. A method for manufacturing the MEMS package is also provided.

20 Claims, 20 Drawing Sheets



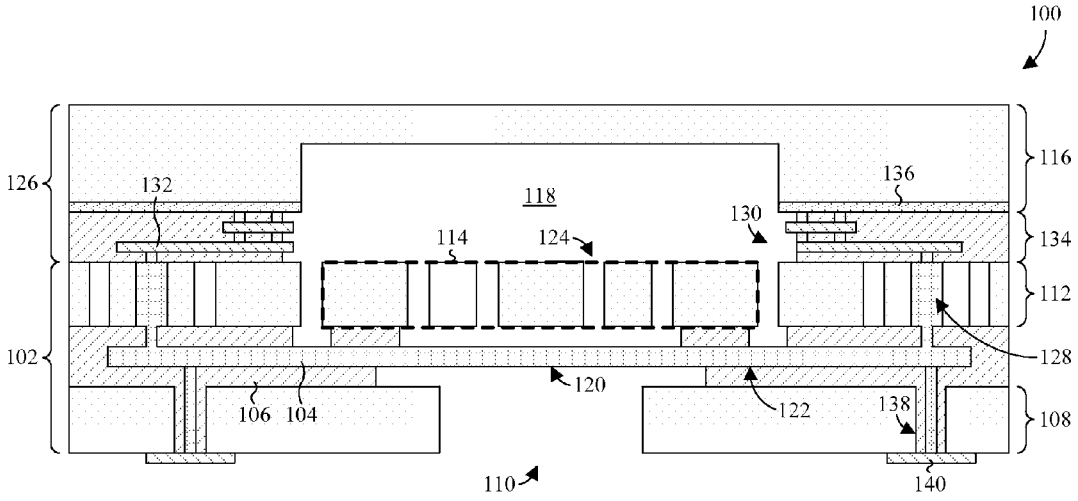

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Fig. 1A

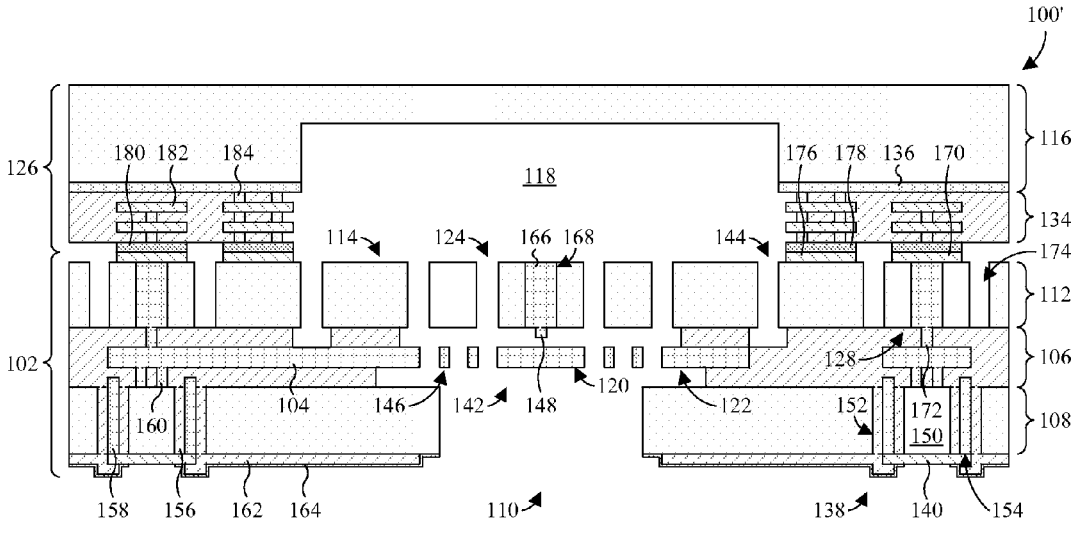
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Fig. 1B

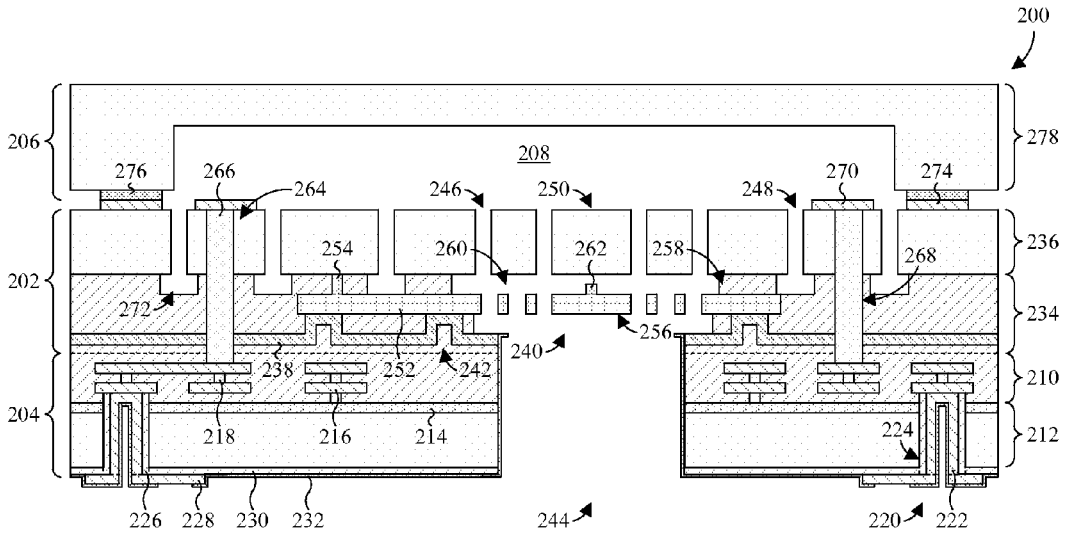
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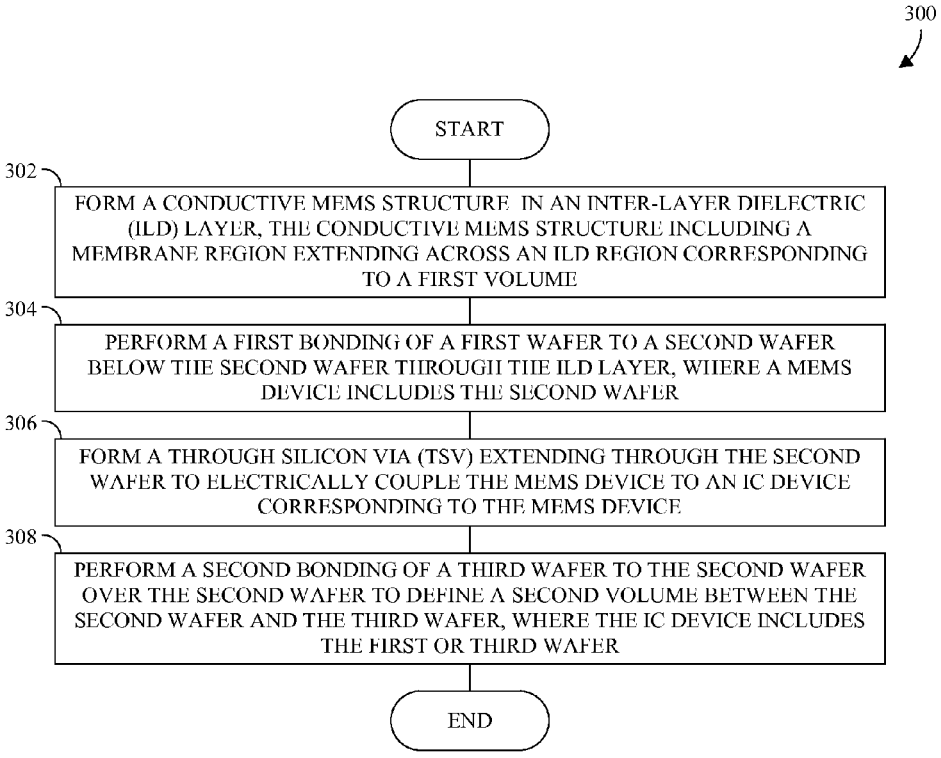
Fig. 2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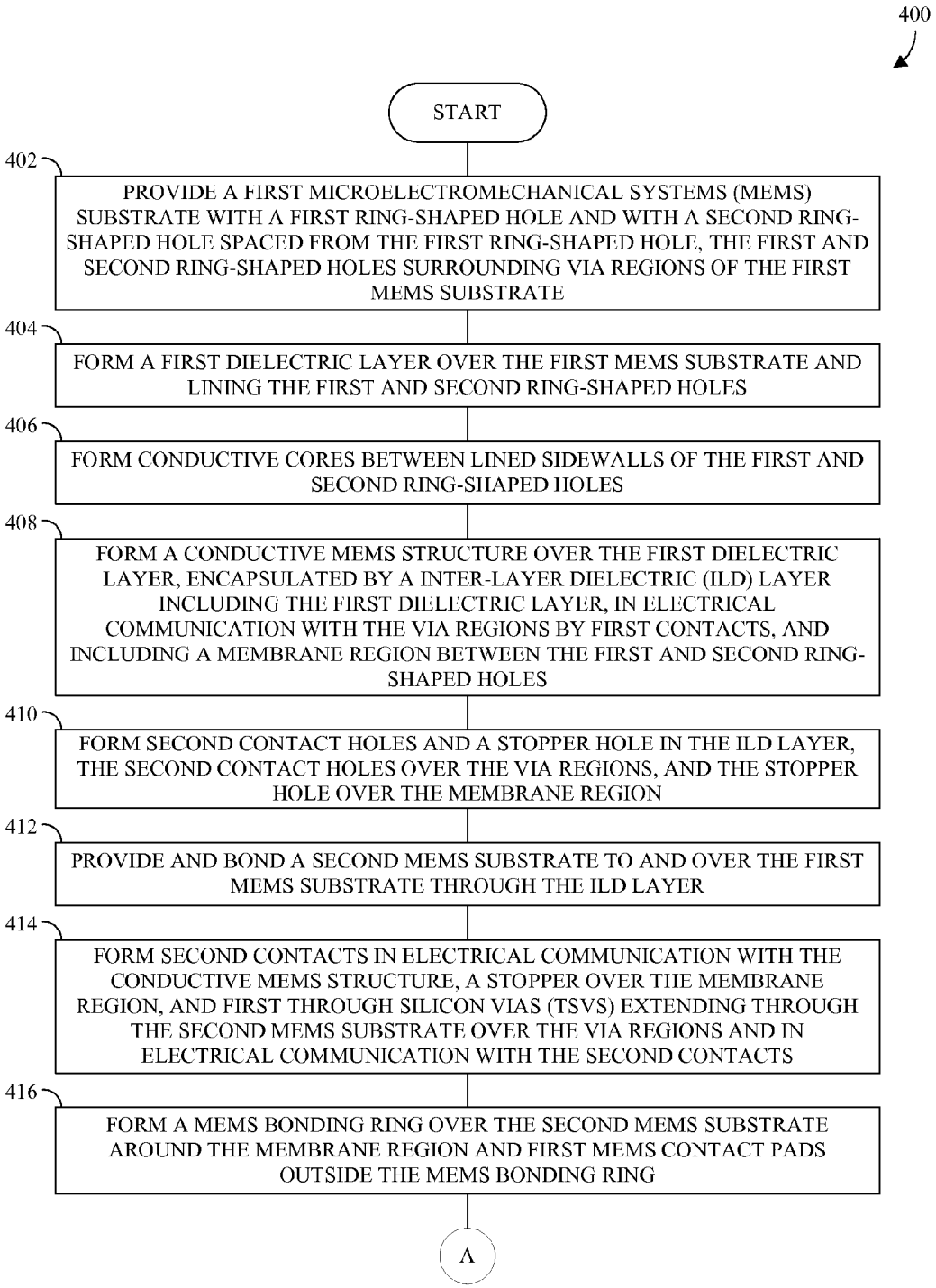
FORM A CONDUCTIVE MEMS STRUCTURE IN AN INTER-LAYER DIELECTRIC (ILD) LAYER, THE CONDUCTIVE MEMS STRUCTURE INCLUDING A MEMBRANE REGION EXTENDING ACROSS AN ILD REGION CORRESPONDING TO A FIRST VOLUME
304
PERFORM A FIRST BONDING OF A FIRST WAFER TO A SECOND WAFER BELOW THE SECOND WAFER THROUGH THE ILD LAYER, WHERE A MEMS DEVICE INCLUDES THE SECOND WAFER
306
FORM A THROUGH SILICON VIA (TSV) EXTENDING THROUGH THE SECOND WAFER TO ELECTRICALLY COUPLE THE MEMS DEVICE TO AN IC DEVICE CORRESPONDING TO THE MEMS DEVICE
308
PERFORM A SECOND BONDING OF A THIRD WAFER TO THE SECOND WAFER OVER THE SECOND WAFER TO DEFINE A SECOND VOLUME BETWEEN THE SECOND WAFER AND THE THIRD WAFER, WHERE THE IC DEVICE INCLUDES THE FIRST OR THIRD WAFER
END

Fig. 3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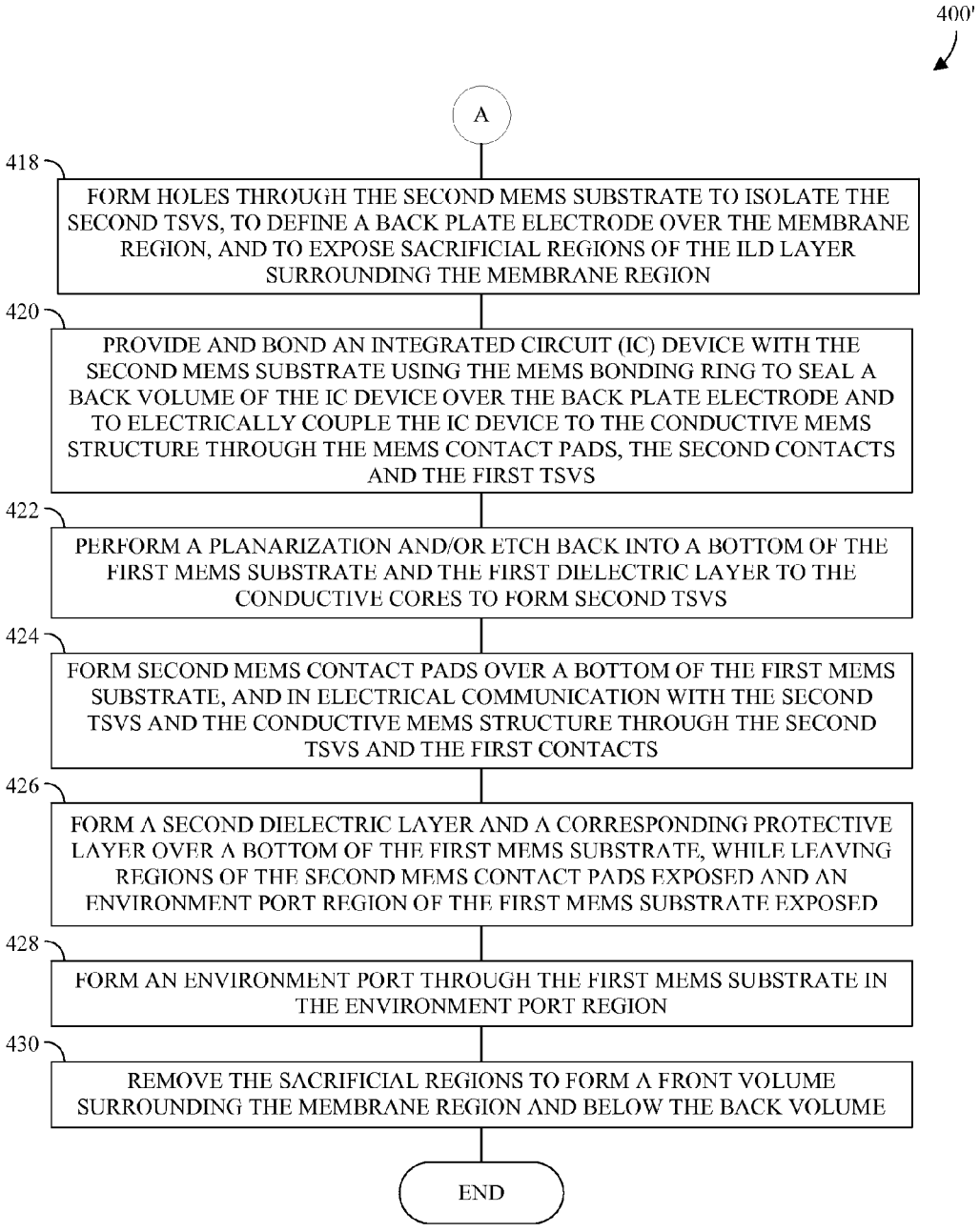
PROVIDE A FIRST MICROELECTROMECHANICAL SYSTEMS (MEMS) SUBSTRATE WITH A FIRST RING-SHAPED HOLE AND WITH A SECOND RING-SHAPED HOLE SPACED FROM THE FIRST RING-SHAPED HOLE, THE FIRST AND SECOND RING-SHAPED HOLES SURROUNDING VIA REGIONS OF THE FIRST MEMS SUBSTRATE
404
FORM A FIRST DIELECTRIC LAYER OVER THE FIRST MEMS SUBSTRATE AND LINING THE FIRST AND SECOND RING-SHAPED HOLES
406
FORM CONDUCTIVE CORES BETWEEN LINED SIDEWALLS OF THE FIRST AND SECOND RING-SHAPED HOLES
408
FORM A CONDUCTIVE MEMS STRUCTURE OVER THE FIRST DIELECTRIC LAYER, ENCAPSULATED BY A INTER-LAYER DIELECTRIC (ILD) LAYER INCLUDING THE FIRST DIELECTRIC LAYER, IN ELECTRICAL COMMUNICATION WITH THE VIA REGIONS BY FIRST CONTACTS, AND INCLUDING A MEMBRANE REGION BETWEEN THE FIRST AND SECOND RING-SHAPED HOLES
410
FORM SECOND CONTACT HOLES AND A STOPPER HOLE IN THE ILD LAYER, THE SECOND CONTACT HOLES OVER THE VIA REGIONS, AND THE STOPPER HOLE OVER THE MEMBRANE REGION
412
PROVIDE AND BOND A SECOND MEMS SUBSTRATE TO AND OVER THE FIRST MEMS SUBSTRATE THROUGH THE ILD LAYER
414
FORM SECOND CONTACTS IN ELECTRICAL COMMUNICATION WITH THE CONDUCTIVE MEMS STRUCTURE, A STOPPER OVER THE MEMBRANE REGION, AND FIRST THROUGH SILICON VIAS (TSVS) EXTENDING THROUGH THE SECOND MEMS SUBSTRATE OVER THE VIA REGIONS AND IN ELECTRICAL COMMUNICATION WITH THE SECOND CONTACTS
416
FORM A MEMS BONDING RING OVER THE SECOND MEMS SUBSTRATE AROUND THE MEMBRANE REGION AND FIRST MEMS CONTACT PADS OUTSIDE THE MEMS BONDING RING
A

Fig. 4A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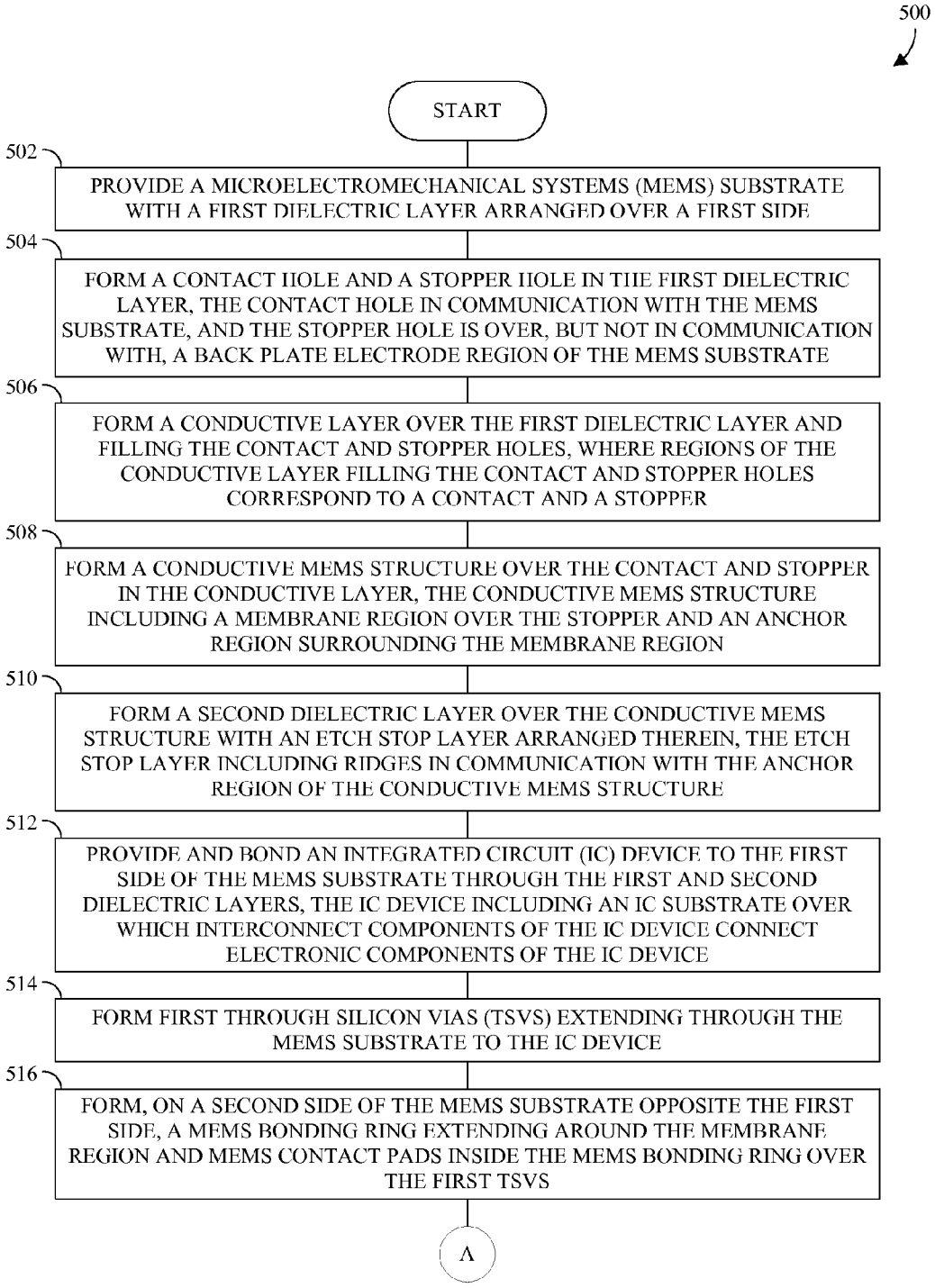
FORM HOLES THROUGH THE SECOND MEMS SUBSTRATE TO ISOLATE THE SECOND TSVS, TO DEFINE A BACK PLATE ELECTRODE OVER THE MEMBRANE REGION, AND TO EXPOSE SACRIFICIAL REGIONS OF THE ILD LAYER SURROUNDING THE MEMBRANE REGION
420
PROVIDE AND BOND AN INTEGRATED CIRCUIT (IC) DEVICE WITH THE SECOND MEMS SUBSTRATE USING THE MEMS BONDING RING TO SEAL A BACK VOLUME OF THE IC DEVICE OVER THE BACK PLATE ELECTRODE AND TO ELECTRICALLY COUPLE THE IC DEVICE TO THE CONDUCTIVE MEMS STRUCTURE THROUGH THE MEMS CONTACT PADS, THE SECOND CONTACTS AND THE FIRST TSVS
422
PERFORM A PLANARIZATION AND/OR ETCH BACK INTO A BOTTOM OF THE FIRST MEMS SUBSTRATE AND THE FIRST DIELECTRIC LAYER TO THE CONDUCTIVE CORES TO FORM SECOND TSVS
424
FORM SECOND MEMS CONTACT PADS OVER A BOTTOM OF THE FIRST MEMS SUBSTRATE, AND IN ELECTRICAL COMMUNICATION WITH THE SECOND TSVS AND THE CONDUCTIVE MEMS STRUCTURE THROUGH THE SECOND TSVS AND THE FIRST CONTACTS
426
FORM A SECOND DIELECTRIC LAYER AND A CORRESPONDING PROTECTIVE LAYER OVER A BOTTOM OF THE FIRST MEMS SUBSTRATE, WHILE LEAVING REGIONS OF THE SECOND MEMS CONTACT PADS EXPOSED AND AN ENVIRONMENT PORT REGION OF THE FIRST MEMS SUBSTRATE EXPOSED
428
FORM AN ENVIRONMENT PORT THROUGH THE FIRST MEMS SUBSTRATE IN THE ENVIRONMENT PORT REGION
430
REMOVE THE SACRIFICIAL REGIONS TO FORM A FRONT VOLUME SURROUNDING THE MEMBRANE REGION AND BELOW THE BACK VOLUME
END

Fig. 4B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START
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PROVIDE A MICROELECTROMECHANICAL SYSTEMS (MEMS) SUBSTRATE WITH A FIRST DIELECTRIC LAYER ARRANGED OVER A FIRST SIDE
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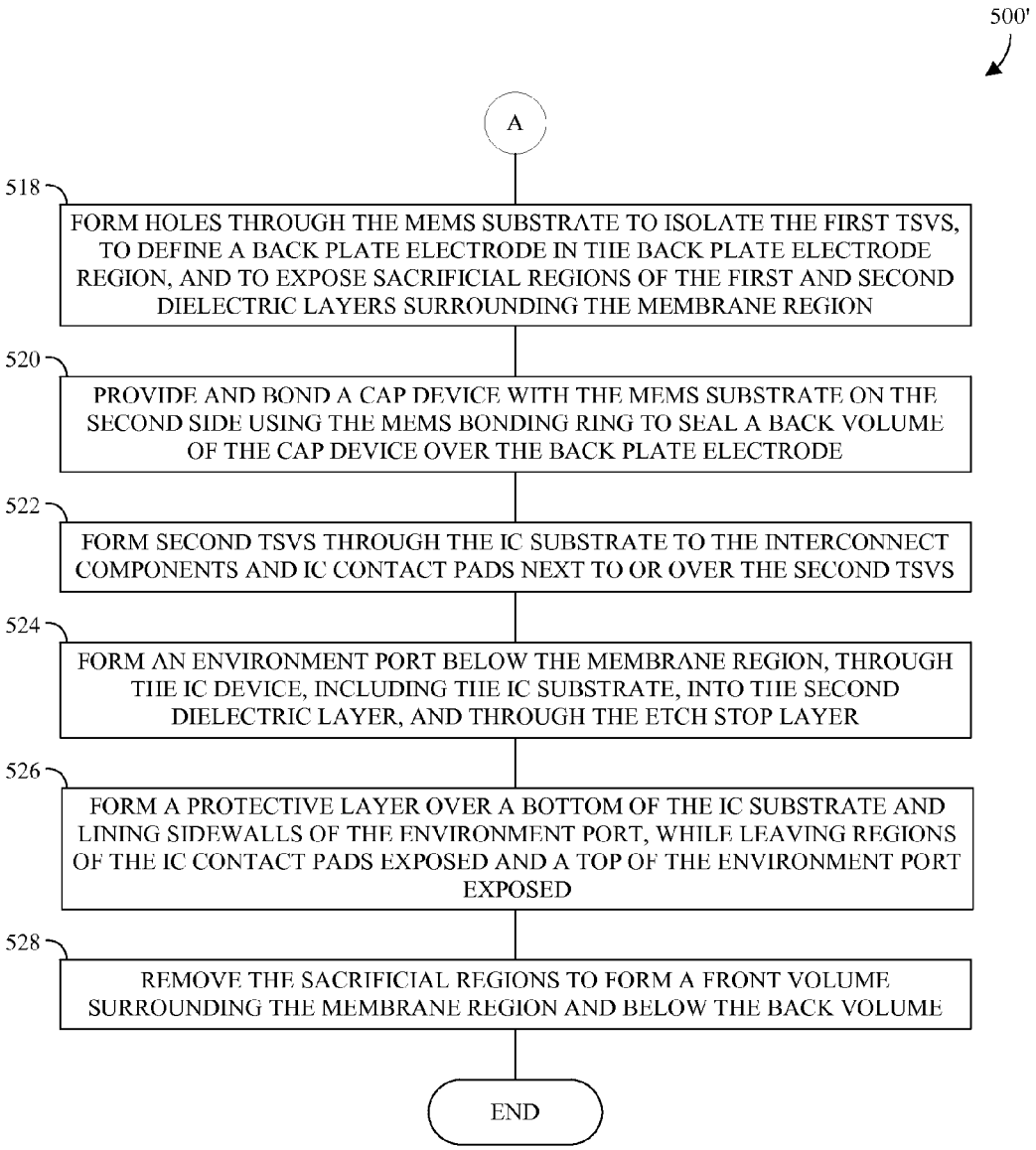
FORM A CONTACT HOLE AND A STOPPER HOLE IN THE FIRST DIELECTRIC LAYER, THE CONTACT HOLE IN COMMUNICATION WITH THE MEMS SUBSTRATE, AND THE STOPPER HOLE IS OVER, BUT NOT IN COMMUNICATION WITH, A BACK PLATE ELECTRODE REGION OF THE MEMS SUBSTRATE
506
FORM A CONDUCTIVE LAYER OVER THE FIRST DIELECTRIC LAYER AND FILLING THE CONTACT AND STOPPER HOLES, WHERE REGIONS OF THE CONDUCTIVE LAYER FILLING THE CONTACT AND STOPPER HOLES CORRESPOND TO A CONTACT AND A STOPPER
508
FORM A CONDUCTIVE MEMS STRUCTURE OVER THE CONTACT AND STOPPER IN THE CONDUCTIVE LAYER, THE CONDUCTIVE MEMS STRUCTURE INCLUDING A MEMBRANE REGION OVER THE STOPPER AND AN ANCHOR REGION SURROUNDING THE MEMBRANE REGION
510
FORM A SECOND DIELECTRIC LAYER OVER THE CONDUCTIVE MEMS STRUCTURE WITH AN ETCH STOP LAYER ARRANGED THEREIN, THE ETCH STOP LAYER INCLUDING RIDGES IN COMMUNICATION WITH THE ANCHOR REGION OF THE CONDUCTIVE MEMS STRUCTURE
512
PROVIDE AND BOND AN INTEGRATED CIRCUIT (IC) DEVICE TO THE FIRST SIDE OF THE MEMS SUBSTRATE THROUGH THE FIRST AND SECOND DIELECTRIC LAYERS, THE IC DEVICE INCLUDING AN IC SUBSTRATE OVER WHICH INTERCONNECT COMPONENTS OF THE IC DEVICE CONNECT ELECTRONIC COMPONENTS OF THE IC DEVICE
514
FORM FIRST THROUGH SILICON VIAS (TSVS) EXTENDING THROUGH THE MEMS SUBSTRATE TO THE IC DEVICE
516
FORM, ON A SECOND SIDE OF THE MEMS SUBSTRATE OPPOSITE THE FIRST SIDE, A MEMS BONDING RING EXTENDING AROUND THE MEMBRANE REGION AND MEMS CONTACT PADS INSIDE THE MEMS BONDING RING OVER THE FIRST TSVS
A

Fig. 5A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FORM HOLES THROUGH THE MEMS SUBSTRATE TO ISOLATE THE FIRST TSVS, TO DEFINE A BACK PLATE ELECTRODE IN THE BACK PLATE ELECTRODE REGION, AND TO EXPOSE SACRIFICIAL REGIONS OF THE FIRST AND SECOND DIELECTRIC LAYERS SURROUNDING THE MEMBRANE REGION
520
PROVIDE AND BOND A CAP DEVICE WITH THE MEMS SUBSTRATE ON THE SECOND SIDE USING THE MEMS BONDING RING TO SEAL A BACK VOLUME OF THE CAP DEVICE OVER THE BACK PLATE ELECTRODE
522
FORM SECOND TSVS THROUGH THE IC SUBSTRATE TO THE INTERCONNECT COMPONENTS AND IC CONTACT PADS NEXT TO OR OVER THE SECOND TSVS
524
FORM AN ENVIRONMENT PORT BELOW THE MEMBRANE REGION, THROUGH THE IC DEVICE, INCLUDING THE IC SUBSTRATE, INTO THE SECOND DIELECTRIC LAYER, AND THROUGH THE ETCH STOP LAYER
526
FORM A PROTECTIVE LAYER OVER A BOTTOM OF THE IC SUBSTRATE AND LINING SIDEWALLS OF THE ENVIRONMENT PORT, WHILE LEAVING REGIONS OF THE IC CONTACT PADS EXPOSED AND A TOP OF THE ENVIRONMENT PORT EXPOSED
528
REMOVE THE SACRIFICIAL REGIONS TO FORM A FRONT VOLUME SURROUNDING THE MEMBRANE REGION AND BELOW THE BACK VOLUME
END

Fig. 5B

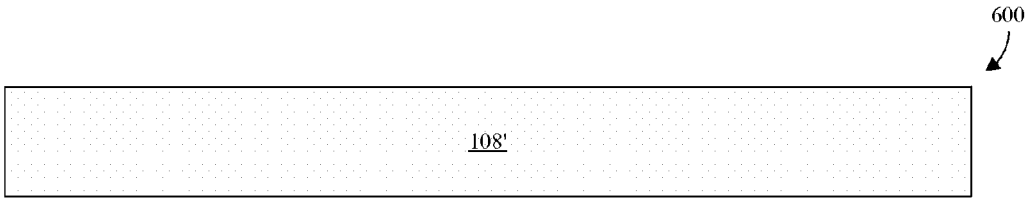
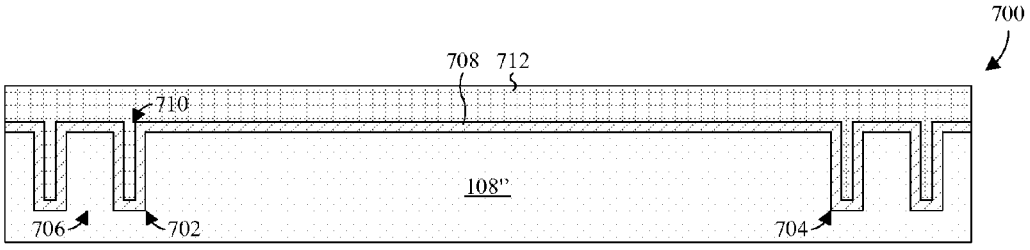


Fig. 6



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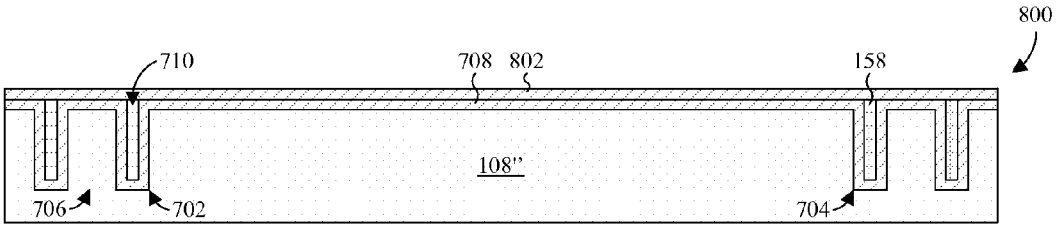
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Fig. 8

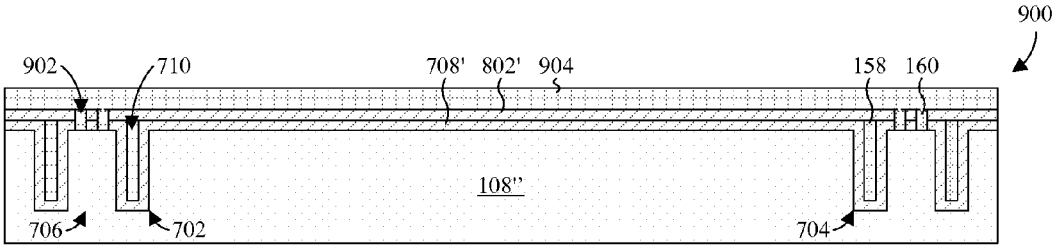
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Fig. 9

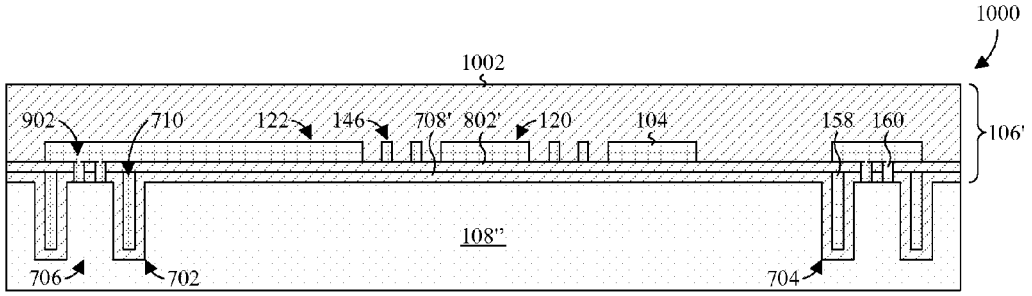
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Fig. 10

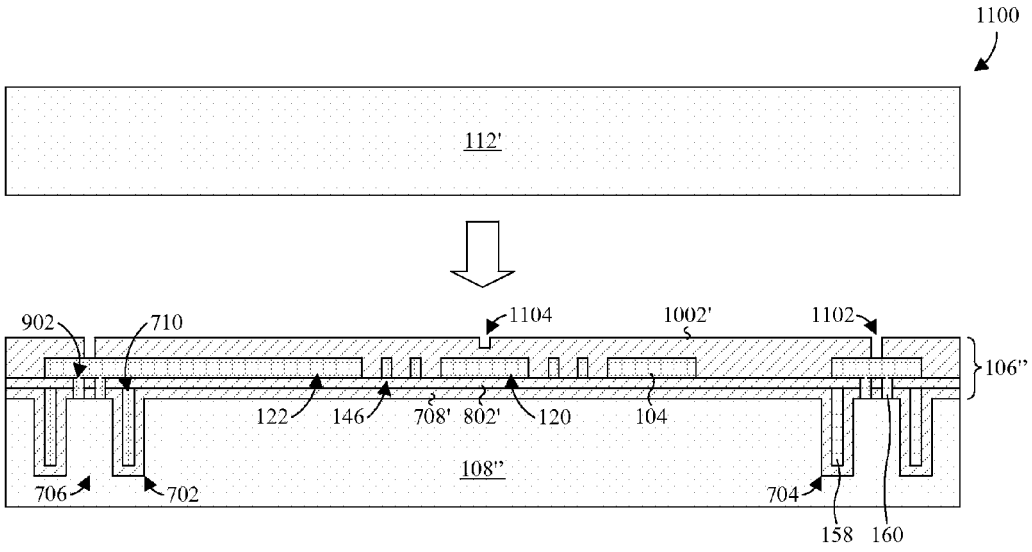
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Fig. 11

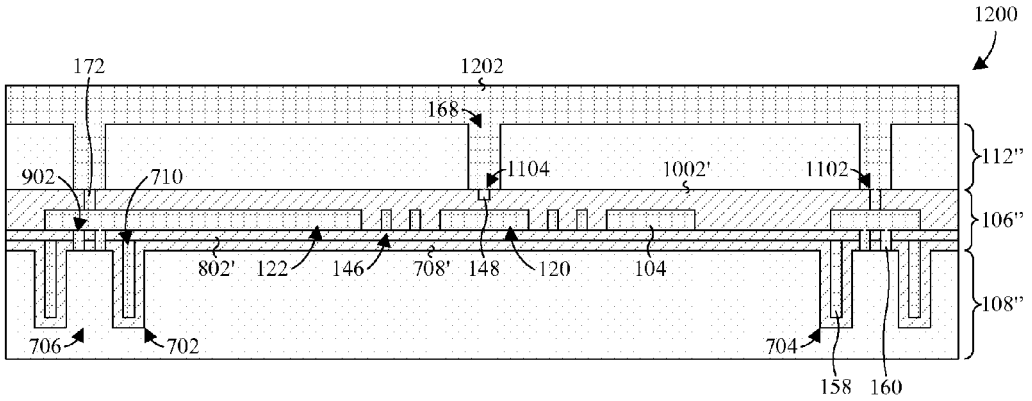
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Fig. 12

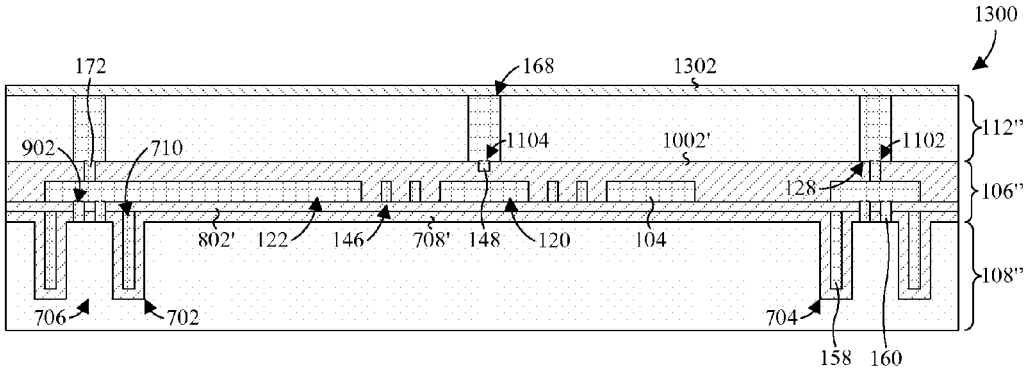
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Fig. 13

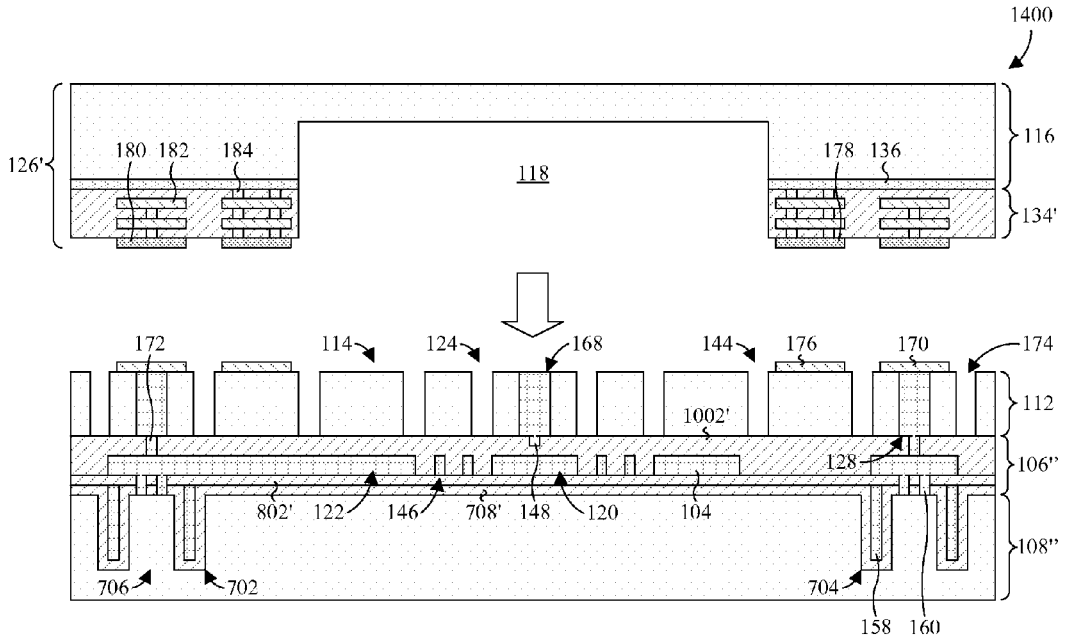
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Fig. 14

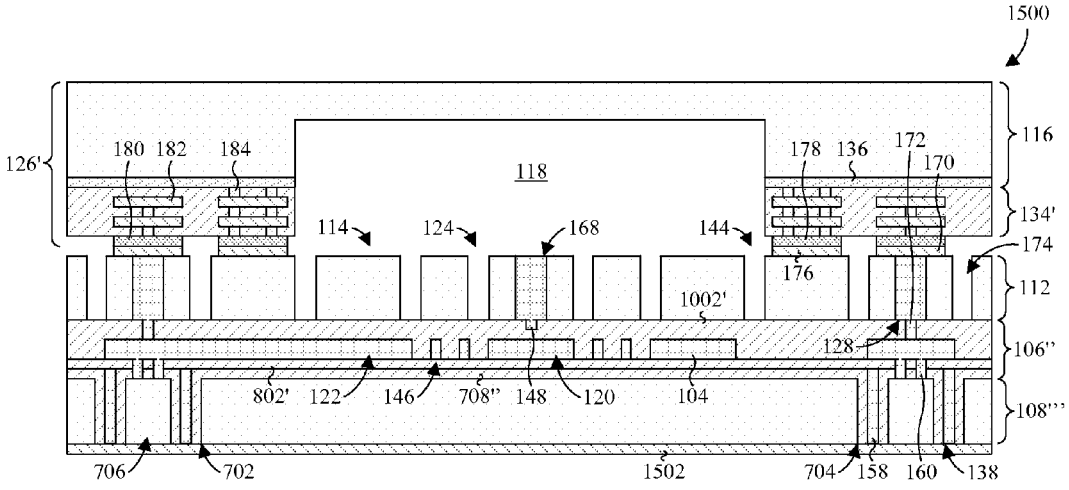
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Fig. 15

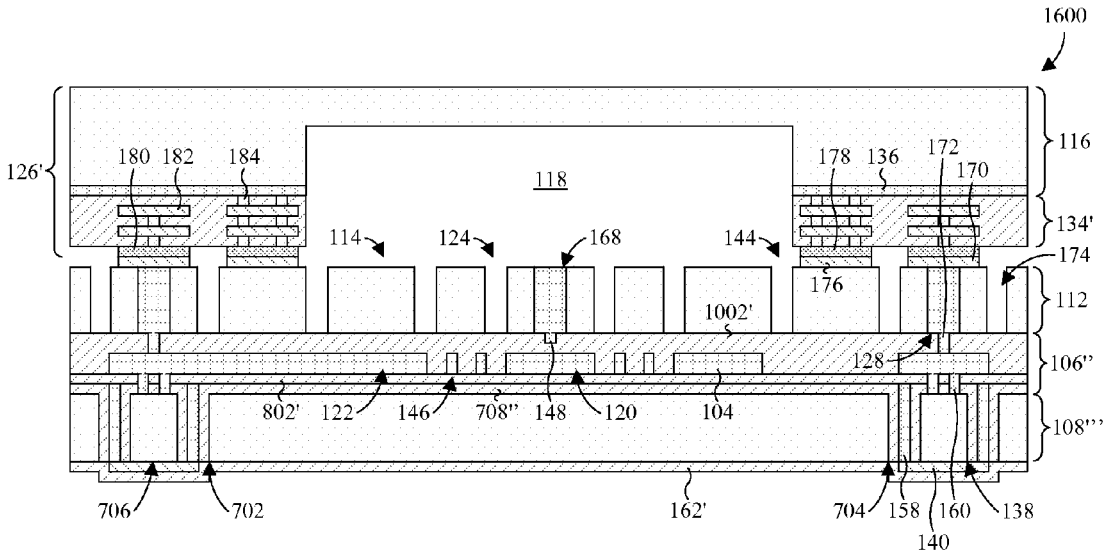
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Fig. 16

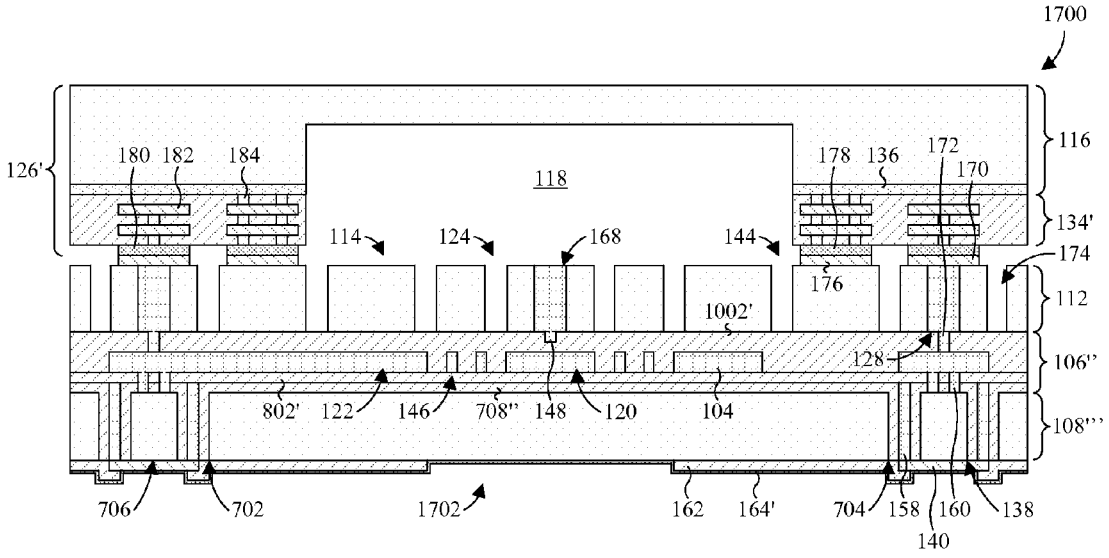
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Fig. 17

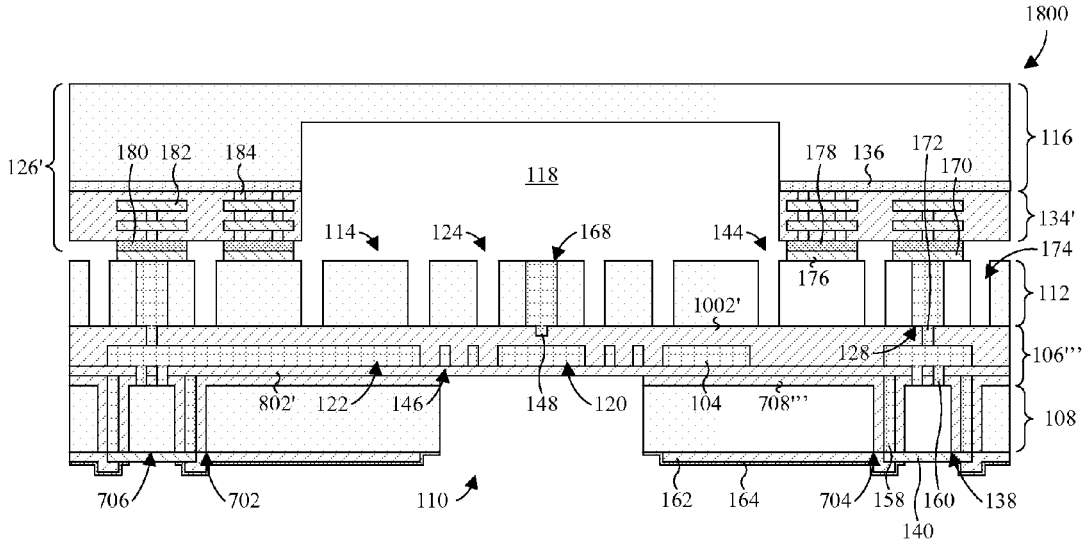
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Fig. 18

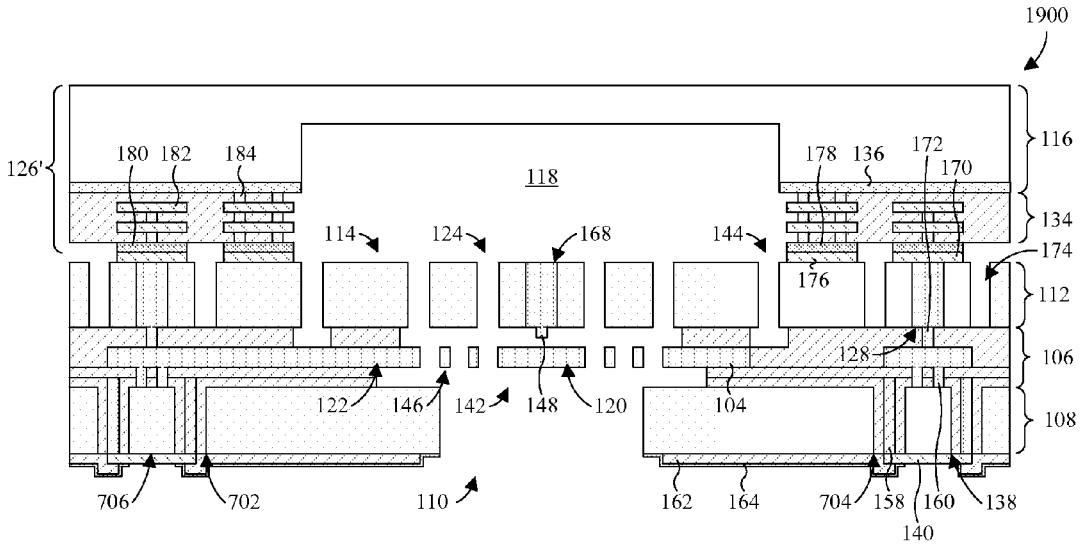
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Fig. 19

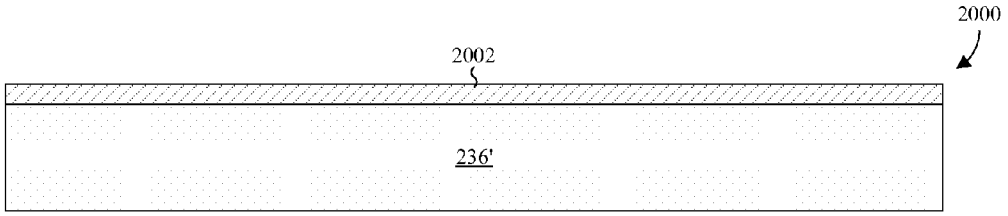
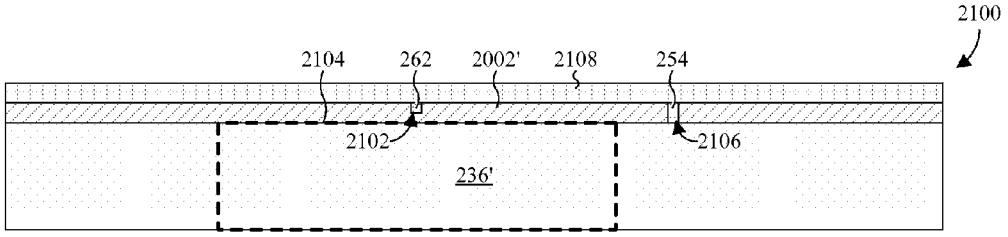


Fig. 20



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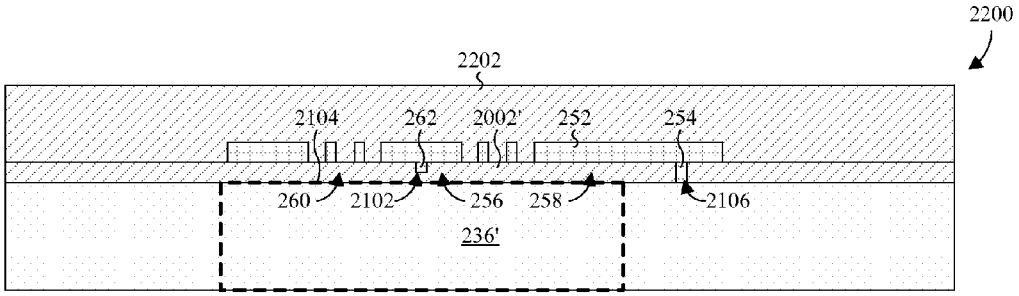
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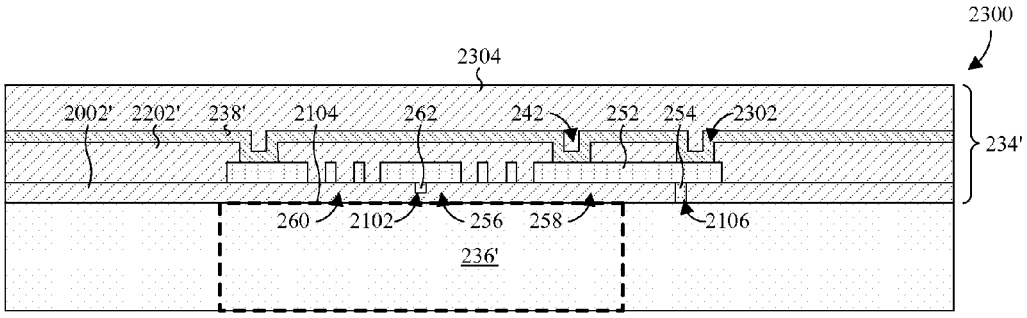
236'

Fig. 22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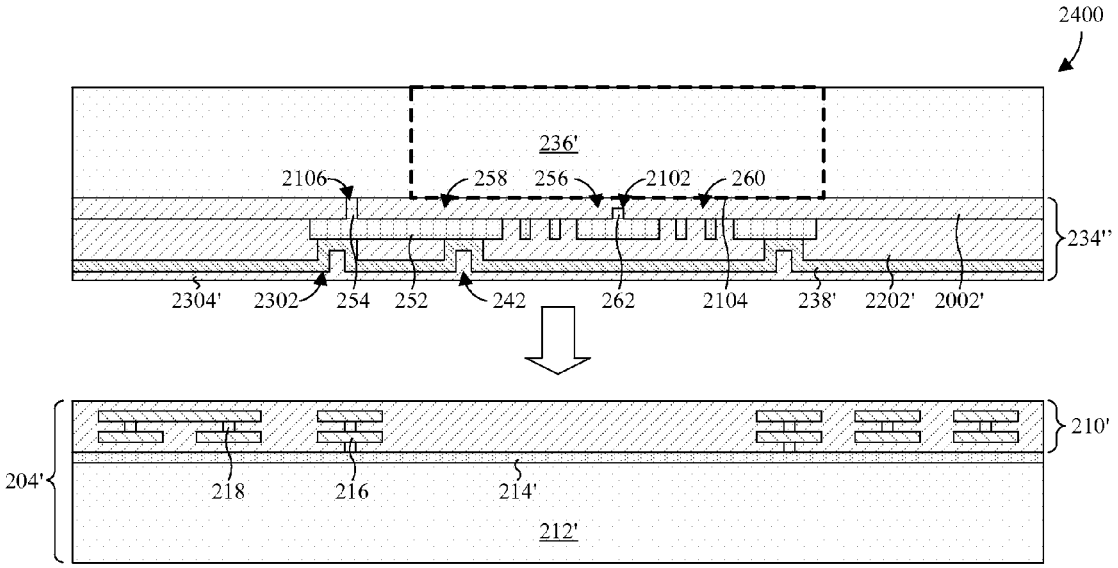
2304
2002'
2202'
238'
2104
262
242
252
254
2302
234'
260
2102
256
258
2106
236'

Fig. 23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236'
2106
258
256
2102
260
234''
2304'
2302
254
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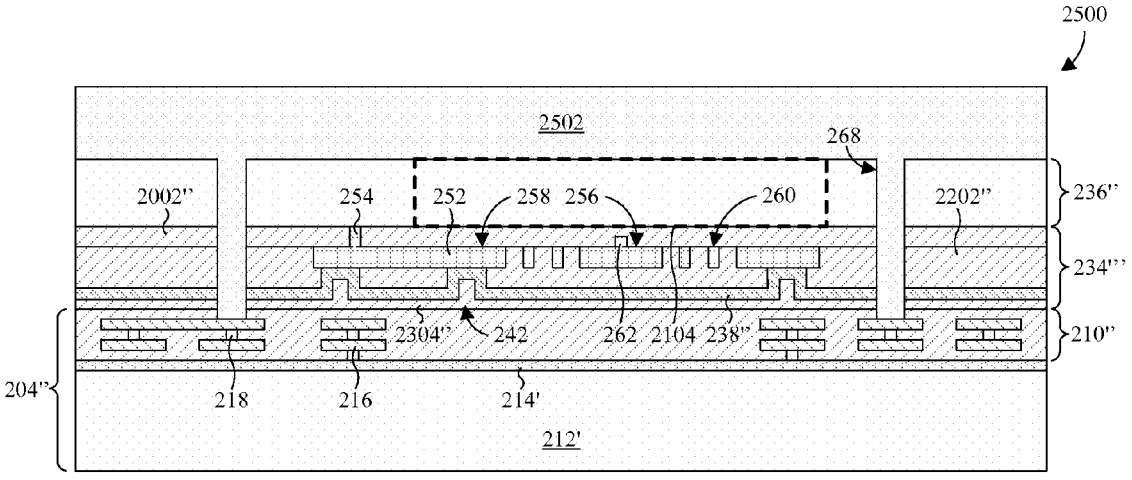
242
262
2104
238'
2202'
2002'
210'
204'
218
216
214'
212'

Fig. 24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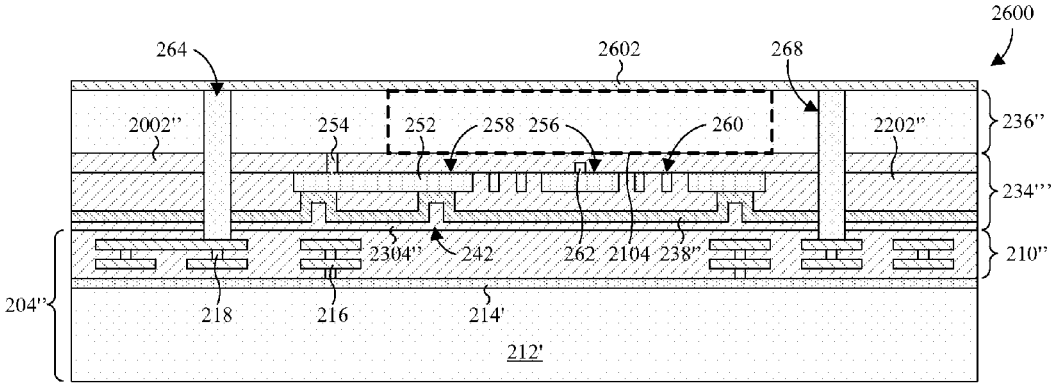
2502
268
2002''
254
252
258
256
260
2202''
236''
234'''
210''
2304''
242
262
2104
238''
204''
218
216
214'
212'

Fig. 25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264
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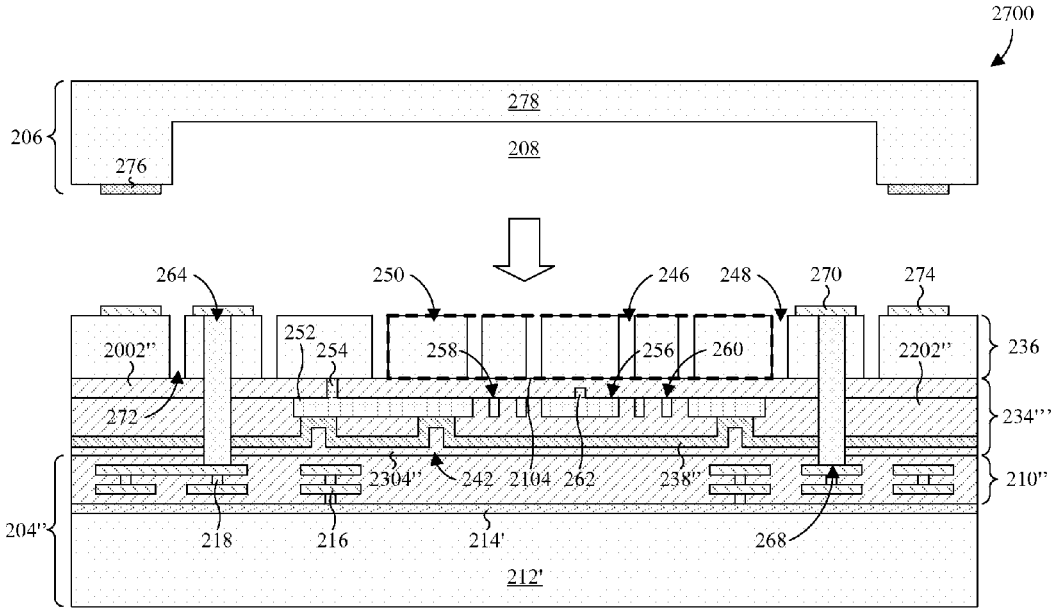
268
2002''
254
252
258
256
260
2202''
236''
234'''
210''
2304''
242
262
2104
238''
204''
218
216
214'
212'

Fig. 26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278
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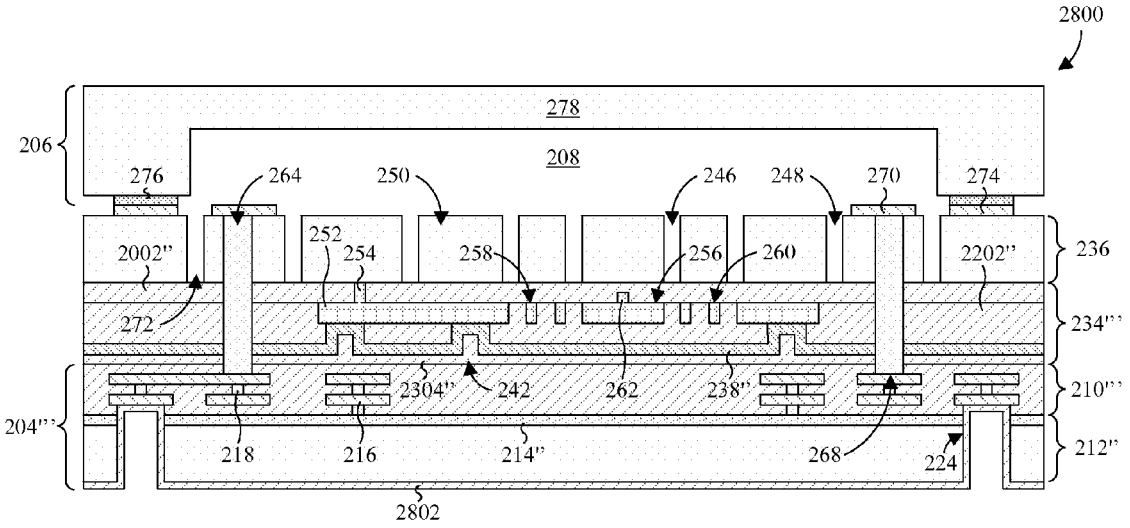
208
276
264
250
246
248
270
274
252
254
2002''
258
256
260
2202''
236
234'''
272
210''
2304''
242
2104
262
238''
204''
218
216
214'
268
212'

Fig. 27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278
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208
276
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250
246
248
270
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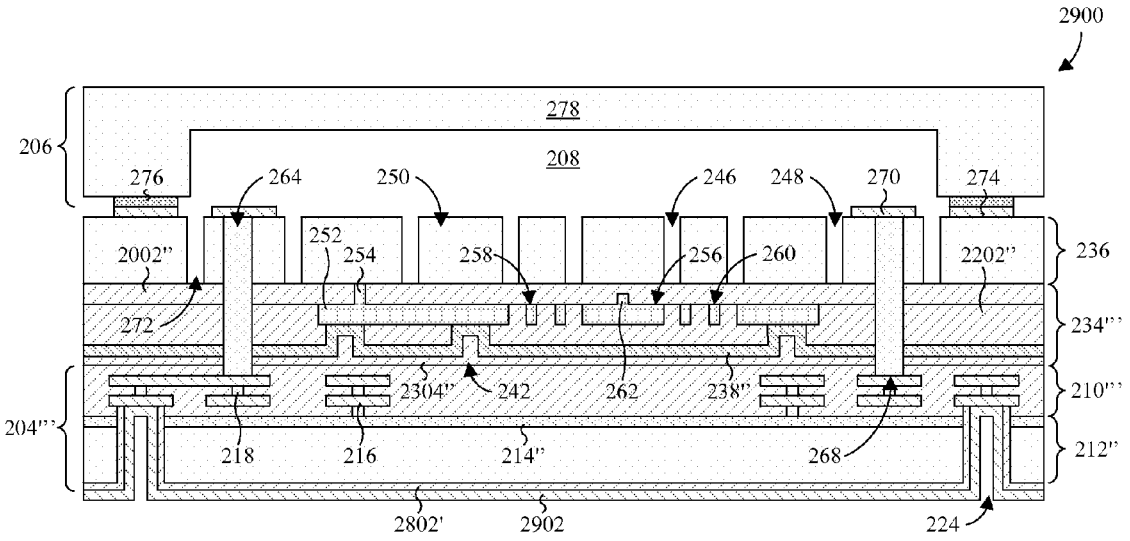
252
254
258
256
260
2002''
2202''
236
272
234'''
2304''
242
262
238''
210'''
204'''
218
216
214''
268
224
212''
2802

Fig. 28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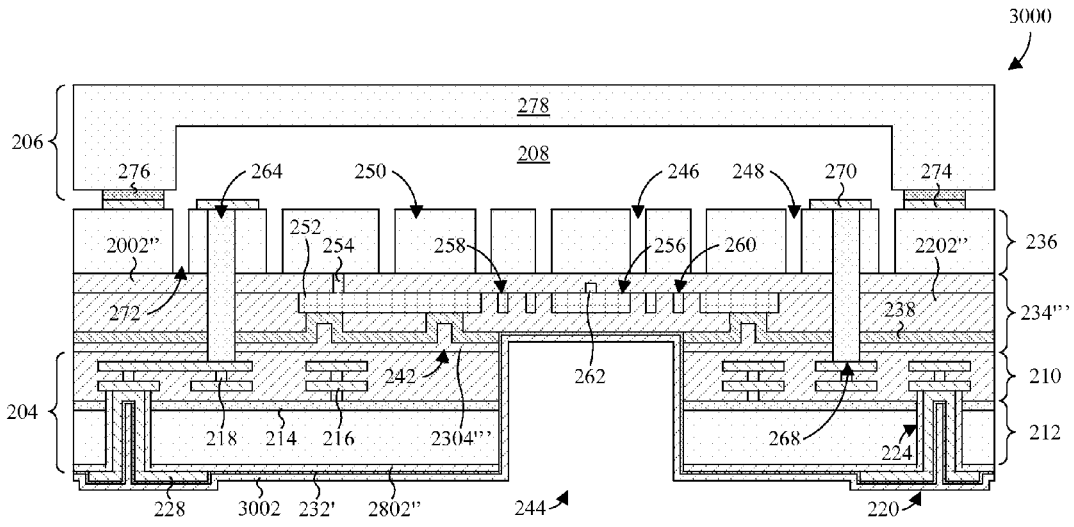
246
248
270
274
252
254
258
256
260
2002''
2202''
236
272
234'''
2304''
242
262
238''
210'''
204'''
218
216
214''
268
212''
2802'
2902
224

Fig. 29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276
264
250
246
248
270
274
2002''
252
254
258
256
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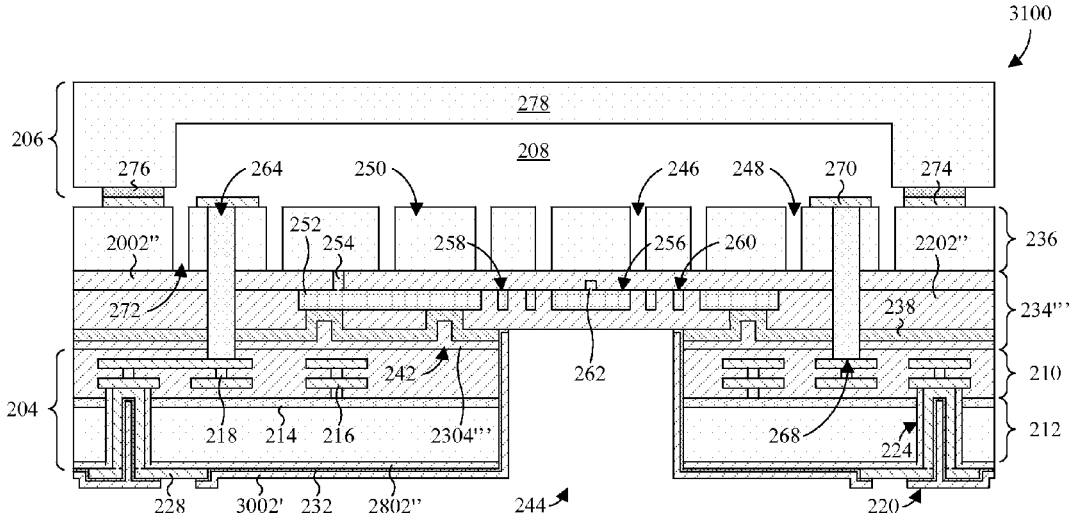
2202''
236
272
238
234'''
242
262
210
204
218
214
216
2304'''
268
212
224
228
3002
232'
2802''
244
220

Fig. 30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274
2002''
252
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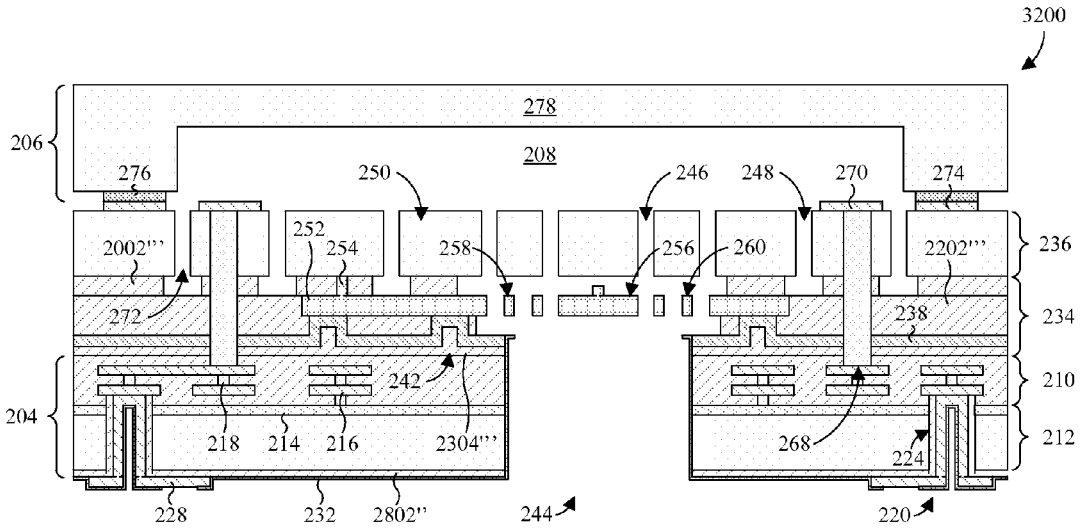
258
256
260
2202''
236
272
238
234'''
242
262
210
204
218
214
216
2304'''
268
212
224
228
3002'
232
2802''
244
220

Fig. 31


3200
278
208
206
276
250
246
248
270
274
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254
258
256
260
2002'''
2202'''
236
272
238
234
242
210
204
218
214
216
2304'''
268
224
212
228
232
2802''
244
220

Fig. 32

METHOD FOR THE INTEGRATION OF A MICROELECTROMECHANICAL SYSTEMS (MEMS) MICROPHONE DEVICE WITH A COMPLEMENTARY METAL-OXIDE-SEMICONDUCTOR (CMOS) DEVICE

BACKGROUND

Microelectromechanical systems (MEMS) devices, such as accelerometers, pressure sensors, and microphones, have found widespread use in many modern day electronic devices. For example, MEMS accelerometers are commonly found in automobiles (e.g., in airbag deployment systems), tablet computers, or in smart phones. For many applications, MEMS devices are electrically connected to application-specific integrated circuits (ASICs) to form complete MEMS systems. Commonly, the connections are formed by wire bonding, but other approaches are also possible.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. **1**A illustrates a cross-sectional view of some embodiments of a microelectromechanical systems (MEMS) package including an environmental MEMS device and an integrated circuit (IC) device connected by through silicon vias (TSVs).

FIG. **1**B illustrates a cross-sectional view of more detailed embodiments of the MEMS package of FIG. **1**A.

FIG. **2** illustrates a cross-sectional view of alternative embodiments of a MEMS package including an environmental MEMS device and an IC device connected by TSVs.

FIG. **3** illustrates a flow chart of some embodiments of a method for manufacturing a MEMS package including an environmental MEMS device and an IC device connected by TSVs.

FIGS. **4**A & **4**B illustrate flow charts of alternative embodiments of a method for manufacturing a MEMS package including an environmental MEMS device and an IC device connected by TSVs.

FIGS. **5**A & **5**B illustrate flow charts of additional alternative embodiments of a method for manufacturing a MEMS package including an environmental MEMS device and an IC device connected by TSVs.

FIGS. **6-32** illustrate a series of cross-sectional views of some embodiments of a MEMS package at various stages of manufacture, the MEMS package including an environmental MEMS device and an IC device connected by TSVs.

DETAILED DESCRIPTION

The present disclosure provides many different embodiments, or examples, for implementing different features of this disclosure. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

Further, spatially relative terms, such as "beneath," "below," "lower," "above," "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

Moreover, "first", "second", "third", etc. may be used herein for ease of description to distinguish between different elements of a figure or a series of figures. "first", "second", "third", etc. are not intended to be descriptive of the corresponding element. Therefore, "a first dielectric layer" described in connection with a first figure may not necessarily corresponding to a "first dielectric layer" described in connection with another figure.

Environmental microelectromechanical systems (MEMS) devices (e.g., MEMs pressure sensors, microphones, etc.) often comprise a membrane and an application-specific integrated circuits (ASIC) die located on a shared semiconductor substrate. The membrane is located over an opening in the substrate that allows the membrane to interact with an ambient environment. The membrane and ASIC die are bonded together by way of one or more bonding wires. To allow the membrane to oscillate in response to a stimuli within the ambient environment and to thereby avoid acoustic performance degradation, the membrane and ASIC are located within a back volume (i.e., a volume over the MEMS device) formed by a chip level packaging process comprising a plastic cap disposed on the shared semiconductor substrate. A challenge or drawback of packaging environmental MEMS devices according to the foregoing methods pertains to parasitic capacitance generated by the bonding wires between the ASIC and MEMS dies. An additional challenge or drawback includes cost of forming the back volume using a chip level packaging, which forms an individual package for each MEMs device.

Therefore, the present application is directed to improved methods for packaging environmental MEMS devices. The improved method uses a wafer level process to form an environmental MEMs device. The wafer level process uses bonding of ASICs to MEMS devices, as well as through silicon vias (TSVs) to connect ASICs and MEMS devices. Even more, the improved method forms the back volumes at the wafer level and, in some embodiments, includes an etch stop to prevent damage from vapor hydrofluoric acid employed for sacrificial oxide removal. The present application is also directed to the semiconductor structure of the MEMS package resulting from performance of the improved method.

With reference to FIG. **1**A, a cross-sectional view **100** of some embodiments of a MEMS package including an environmental MEMS device **102** is provided. The environmental MEMS device **102** is, for example, a microphone, a pressure sensor, or any other device interfacing with the external environment.

A conductive MEMS structure **104** of the environmental MEMS device **102** is arranged in a first inter-layer dielectric

(ILD) layer **106**. A first side of the first ILD layer **106** abuts a first substrate **108** having an environment port **110** that is in communication with an ambient environment. A second side of the first ILD layer **106**, opposite the first side, abuts a second substrate **112** within which the environmental MEMS device **102** is at least partially formed. The second substrate **112** includes a back plate electrode **114**, and is further coupled to third substrate **116** to define a back volume **118** therebetween over the back plate electrode **114**. In some embodiments, the first, second and third substrates **108**, **112**, **116** are bulk semiconductor substrates including one or more of, for example, silicon, germanium, silicon carbide, a group III element, and a group V element. In other embodiments, one or more of the first substrate **108**, the second MEMS substrate **112**, and the third substrate **116** are silicon-on-insulator (SOI) substrates or polysilicon-on-insulator (POI) substrates.

The conductive MEMS structure **104** includes a membrane region **120** surrounded by an anchor region **122**. The membrane region **120** has a first side in communication with the environment port **110** and a second side, opposite the first side, in communication with the back volume **118**. The second side of the membrane region **120** is in communication with the back volume **118** by way of one or more openings **124** in the second substrate **112**. In some embodiments, an etch stop layer (not shown) is arranged in the first ILD layer **106** below the conductive MEMS structure **104** to provide a lateral etch stop for regions of the ILD layer **106** below the anchor regions **122**.

In some embodiments, an integrated circuit (IC) device **126** is formed over and/or within the third substrate **116**. In other embodiments, the IC device **126** is formed over a top of the first substrate **108**.

One or more first TSVs **128** extend through the second substrate **112** to electrically couple the IC device **126** with the MEMS device **102**, including the conductive MEMS structure **104** and the back plate electrode **114**. In such embodiments, the first TSVs **128** are electrically coupled to the IC device **126** by a back-end-of-the-line (BEOL) stack **130** of the IC device **126**. The BEOL stack **130** includes one or more metal layers **132** disposed within a second ILD layer **134** abutting an electronic components layer **136** of the IC device **126**. Similarly, one or more second TSVs **138** extend through the first substrate **108** to electrically coupled the IC device **126** and/or the MEMS device **102** to contact pads **140** arranged on a bottom of the first substrate **108**.

By forming a connection between the IC device **126** and the environmental MEMS device **102** using one or more TSVs **128**, **138**, the parasitic capacitance between the MEMS device **102** and the IC device **126** is reduced. Furthermore, by forming the back volume **118** of the MEMS device **102** using the third substrate **116**, the overall cost of the MEMS device **102** can be reduced since the back volume **118** is formed using a wafer level process (in contrast to a package level process that forms the back volume **118** during packaging of the system).

With reference to FIG. **1**B, a cross-sectional view **100'** of some more detailed embodiments of a MEMS package is provided. The MEMS package includes a MEMS device **102** and an IC device **126** arranged over the MEMS device **102** with a back volume **118** arranged between the MEMS and IC devices **102**, **126**. The MEMS device **102** and the IC device **126** each correspond to a die, and/or a region of a wafer before singulation. The MEMS device **102** is an environmental MEMS device, such as a microphone, pressure sensor, or any other device interfacing with the external environment. The IC device **126** supports MEMS device operations and is, for example, an ASIC.

A first MEMS substrate **108** and a second MEMS substrate **112**, of the MEMS device **102**, are arranged vertically on opposite sides of a first ILD layer **106** of the MEMS device **102**. The first and second MEMS substrates **108**, **112** are substrates over and/or within which the MEMS device **102** is formed. The second MEMS substrate **112** is arranged over and bonded to the first MEMS substrate **108**, typically with a fusion bond at the interface between the first ILD layer **106** and the second MEMS substrate **112**. Further, a front volume **142** is arranged in the first ILD layer **106** between the first and second MEMS substrates **108**, **112**. The first and second MEMS substrates **108**, **112** are typically bulk semiconductor substrates including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. In other embodiments, the first and second MEMS substrates **108**, **112** are POI or SOI substrates. The first ILD layer **106** typically is or otherwise includes an oxide, such as silicon dioxide.

An environment port **110** extends through the first MEMS substrate **108** to the front volume **142** and inter-volume holes **124** extend through the second MEMS substrate **112** between the front and back volumes **142**, **118**. Further, a back plate isolation hole **144** extends through the second MEMS substrate **112** to the first ILD layer **106** around the periphery of the front volume **142**. In some embodiments, the back plate isolation hole **144** further extends into the first ILD layer **106**. The back plate isolation hole **144** defines a back plate electrode **114** therebetween in the second MEMS substrate **112** over the front volume **142**. The back plate electrode **114** is employed for MEMS device operations, and the back plate isolation hole **144** is employed to electrically isolate the back plate electrode **114**. The back plate electrode **114** typically corresponds to a highly doped region of the second MEMS substrate **112**.

A conductive MEMS structure **104** of the MEMS device **102** is arranged in the first ILD layer **106** between the first and second MEMS substrates **108**, **112** and extends laterally across the front volume **142**. In some embodiments, the conductive MEMS structure **104** includes a membrane region **120** arranged within the front volume **142** and connected to peripheral, an anchor region **122** surrounding the membrane region **120**. Where the MEMS device **102** is a microphone, the membrane region **120** is spaced from and connected to the anchor region **122** by spring regions **146**. In operation, the membrane region **120** vibrates or otherwise deflects in accordance with sound received through the environment port **110**. Further, capacitive coupling between the back plate electrode **114** and the membrane region **120** is employed to measure the deflection. Where the MEMS device **102** is a pressure sensor, the membrane region **120** is directly connected to the anchor region **122** and bisects the front volume **142** into two independent sub-volumes. In operation, the membrane region **120** deflects in proportion to the difference between the environmental pressure and pressure in the back volume **118**. Further, capacitive coupling between the back plate electrode **114** and the membrane region **120** is employed to measure the deflection. The conductive MEMS structure **104** typically is or otherwise includes polysilicon.

A stopper **148** of the MEMS device **102** is arranged in the front volume **142** below the second MEMS substrate **112** between the second MEMS substrate **112** and the conductive MEMS structure **104**. The stopper **148** stops deflecting regions of the conductive MEMS structure **104**, such as the membrane region **120**, from sticking to the second MEMS

substrate **112** and from overextending in the vertical direction towards the second MEMS substrate **112**. This advantageously reduces the likelihood of damage to the MEMS device **102** and increases the useful life of the MEMS device **102**. The stopper **148** is or otherwise includes, for example, polysilicon or a dielectric, such as silicon dioxide.

First TSVs **138** of the MEMS device **102** extend through the first MEMS substrate **108** and, in some embodiments, into the first ILD layer **106**. The first TSVs **138** include first conductive structures **150** arranged in corresponding first TSV holes **152**. The first conductive structures **150** typically line sidewalls of the first TSV holes **152** or fill the first TSV holes **152**. In some embodiments, first dielectric liners **154** of the first TSVs **138** line sidewalls of the first TSV holes **152** between the first conductive structures **150** and the sidewalls. The first dielectric liners **154** include dielectric structures **156** and, in some embodiments, conductive cores **158** arranged within the dielectric structures **156**. The dielectric structures **156** typically are or otherwise include an oxide, such as silicon dioxide, and the conductive cores **158** typically are or otherwise include polysilicon. The first conductive structures **150** typically are or otherwise include highly doped silicon or semiconductor materials. The first TSVs **138** electrically couple first MEMS contact pads **140** of the MEMS device **102** arranged on the bottom of the first MEMS substrate **108** to the conductive MEMS structure **104** with first MEMS contacts **160** of the MEMS device **102**. The first MEMS contacts **160** extend through the first ILD layer **106** between the conductive MEMS structure **104** and the first MEMS substrate **108**, and typically are or otherwise include polysilicon or a metal, such as tungsten. The first MEMS contact pads **140** electrically couple the MEMS device **102** with external devices, and typically are or otherwise include metal, such as aluminum, copper, or aluminum copper.

A dielectric layer **162** and a corresponding protective layer **164**, of the MEMS device **102**, are arranged over the bottom of the first MEMS substrate **108** and, in some embodiments, partially over the first MEMS contact pads **140**. The dielectric layer **162** and the protective layer **164** provide electrical insulation to the first MEMS substrate **108**. Further, the protective layer **164** is arranged over a bottom of the dielectric layer **162** to protect the dielectric layer **162** from, for example, hydrofluoric acid used during the formation of the MEMS package. The dielectric layer **162** typically is or otherwise includes an oxide, such as silicon dioxide, and the protective layer **164** typically is or otherwise includes low stress nitride, aluminum nitride, aluminum oxide, or silicon carbide.

Second TSVs **128** of the MEMS device **102** extend through the second MEMS substrate **112**. The second TSVs **128** include second conductive structures **166** arranged in corresponding second TSV holes **168**. The second conductive structures **166** typically line sidewalls of the second TSV holes **168** or fill the second TSV holes **168**. In some embodiments, second dielectric liners (not shown) of the second TSVs **128** line sidewalls of the second TSV holes **168** between the second conductive structures **166** and the sidewalls. The second dielectric liners typically are or otherwise include an oxide, such as silicon dioxide. The second conductive structures **166** typically are or otherwise include polysilicon or a metal. The second TSVs **128** electrically couple the back plate electrode **114** and second MEMS contact pads **170** to the conductive MEMS structure **104** with second MEMS contacts **172** of the MEMS device **102**. The second MEMS contacts **172** extend through the first ILD layer **106** between the conductive MEMS structure **104** and the second MEMS substrate **112**, and typically are or otherwise include polysilicon or a metal, such as tungsten. The second MEMS contact pads **170** are arranged on the top of the second MEMS substrate **112** and electrically couple the MEMS device **102** with the IC device **126** and, in some embodiments, with other devices. The second MEMS contact pads **170** typically are or otherwise include metal, such as aluminum, copper, aluminum copper, copper tine, or gold.

TSV isolation holes **174** of the MEMS device **102** are arranged through the second MEMS substrate **112** to the first ILD layer **106** and around the second TSVs **128**. In some embodiments, the TSV isolation holes **174** extend into the first ILD layer **106**. The TSV isolation holes **174** electrically isolate the second TSVs **128** from neighboring regions of the second MEMS substrate **112** with air gaps.

A MEMS bonding ring **176** of the MEMS device **102** is arranged on the MEMS device **102**, and an IC bonding ring **178** of the IC device **126** is arranged over the MEMS bonding ring **176** on the IC device **126**. The MEMS and IC bonding rings **176**, **178** have like footprints and extend around the back volume **118**. The MEMS and IC bonding rings **176**, **178** bond the MEMS device **102** to the IC device **126** with a bond, typically a eutectic bond, at the interface between the MEMS and IC bonding rings **176**, **178**. Where the MEMS device **102** is a pressure sensor, in some embodiments, the bond hermetically seals the back volume **118** with a reference pressure employed for pressure measurements. The MEMS bonding ring **176** typically is or otherwise includes a metal, such as aluminum, copper, aluminum copper, copper tin, or gold, and the IC bonding ring **178** typically is or otherwise includes a metal, such as germanium, copper, or copper tin.

An IC substrate **116** of the IC device **126** is arranged over the second MEMS substrate **112** with a second ILD layer **134** of the IC device **126** arranged between the IC substrate **116** and the second MEMS substrate **112**. The IC substrate **116** is a substrate over and/or within which the IC device **126** is formed. The back volume **118** extends from the second MEMS substrate **112**, through the second ILD layer **134**, and partially into the IC substrate **116**. The IC substrate **116** is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. In other embodiments, the IC substrate **116** is a POI or SOI substrate. The second ILD layer **134** typically is or otherwise includes an oxide, such as silicon dioxide.

An electronic components layer **136** of the IC device **126** is arranged over and/or within a bottom of the IC substrate **116**. The electronic components layer **136** includes electronic components electrically connected with each other and IC contact pads **180** of the IC device **126** by interconnect components **182**, **184** of the IC device **126** arranged within the second ILD layer **134**. The electronic components include, for example, one or more of transistors, capacitors, resistors, inductors, and diodes. The interconnect components **182**, **184** include, for example, one or more of wires **182**, vias, and contacts **184**. The wires **182** typically are or otherwise include a metal, such as aluminum cooper, and the vias and contacts **184** typically are or otherwise include a metal, such as tungsten. The IC contact pads **180** electrically couple the IC device **126** with the MEMS device **102** through the second MEMS contact pads **170** and, in some embodiments, with other devices. The IC contact pads **180** typically are or otherwise include metal, such as aluminum, cooper, aluminum copper, copper tin, or gold.

With reference to FIG. **2**, a cross-sectional view **200** of alternative embodiments of a MEMS package is provided. The MEMS package includes a MEMS device **202** and an IC device **204** arranged over the MEMS device **202**. Further, the MEMS package includes a cap device **206** arranged over the

MEMS device **202** with a back volume **208** arranged between the MEMS and cap devices **202**, **206**. The MEMS, IC, and cap devices **202**, **204**, **206** each correspond to a die, and/or a region of a wafer before singulation. The MEMS device **202** is an environmental MEMS device, such as a microphone, pressure sensor, or any other device interfacing with the external environment. The IC device **204** supports MEMS device operations and is, for example, an ASIC.

A first ILD layer **210** of the IC device **204** is arranged over an IC substrate **212** of the IC device **204**. The IC substrate **212** is a substrate over and/or within which the IC device **204** is arranged. An electronic components layer **214** of the IC device **204** is arranged over and/or within the IC substrate **212**, and electronic components of the electronic components layer **214** are electrically connected with each other by interconnect components **216**, **218** of the IC device **204** arranged within the first ILD layer **210**. The electronic components include, for example, one or more of transistors, capacitors, resistors, inductors, and diodes. The interconnect components **216**, **218** include, for example, one or more of wires **216**, vias, and contacts **218**. The wires **216** typically are or otherwise include a metal, such as aluminum, copper, or aluminum copper, and the vias and contacts **218** typically are or otherwise include a metal, such as tungsten or copper. The IC substrate **212** is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element and a group V element. In other embodiments, the IC substrate **212** is a POI or SOI substrate. The first ILD layer **210** typically is or otherwise includes an oxide, such as silicon dioxide.

First TSVs **220** of the IC device **204** extend through the IC substrate **212** into the first ILD layer **210** to the interconnect components **216**, **218**. The first TSVs **220** include first conductive structures **222** arranged in corresponding first TSV holes **224**. The first conductive structures **222** typically line sidewalls of the first TSV holes **224** or fill the first TSV holes **224**. In some embodiments, first dielectric liners **226** of the first TSVs **220** line sidewalls of the first TSV holes **224** between the first conductive structures **222** and the sidewalls. The first dielectric liners **226** typically are or otherwise include an oxide, such as silicon dioxide. The first conductive structures **222** typically are or otherwise include a metal, such as aluminum, copper, or aluminum copper. The first TSVs **220** electrically couple IC contact pads **228** of the IC device **204** arranged on the bottom of the IC substrate **212** to the interconnect components **216**, **218**. The IC contact pads **228** electrically couple the IC device **204** with external devices, and typically are or otherwise include metal, such as aluminum, copper, or aluminum copper.

A dielectric layer **230** and a corresponding protective layer **232**, of the IC device **204**, are arranged over the bottom of the IC substrate **212**. The dielectric layer **230** is arranged between the IC substrate **212** and the IC contact pads **228** for electrical isolation. Further, the protective layer **232** is arranged over the bottom of the dielectric layer **230** to protect the dielectric layer **230** from, for example, hydrofluoric acid used during the formation of the MEMS package. In some embodiments, the protective layer **232** extends partially over the IC contact pads **228** and/or lines the first conductive structures **222**. The dielectric layer **230** typically is or otherwise includes an oxide, such as silicon dioxide, and the protective layer **232** typically is or otherwise includes low stress nitride, aluminum nitride, aluminum oxide, or silicon carbide.

A second ILD layer **234** of the MEMS device **202** is arranged over the first ILD layer **210** between the first ILD layer **210** and a MEMS substrate **236** of the MEMS device **202**. The MEMS substrate **236** is a substrate over and/or within which the MEMS device **202** is arranged. Typically, the MEMS device **202** is bonded to the IC device **204** by a fusion bond at the interface between the first and second ILD layers **210**, **234**. An etch stop layer **238** is arranged in the second ILD layer **234**, and a front volume **240** is arranged in the second ILD layer **234** over the etch stop layer **238** between the etch stop layer **238** and the MEMS substrate **236**. In some embodiments, the etch stop layer **238** includes ridges **242** extending vertically up towards the MEMS substrate **236** to define a lateral etch stop for sidewalls of the front volume **240** and to define an anchor region of the second ILD layer **234** around the periphery of the front volume **240**. The etch stop layer **238** typically is or otherwise includes low stress nitride, aluminum nitride, aluminum oxide, or silicon carbide. The MEMS substrate **236** is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. However, in other embodiments, the MEMS substrate **236** is a SOI substrate or a POI substrate. The second ILD layer **234** typically is or otherwise includes an oxide, such as silicon dioxide.

An environment port **244** extends through the IC substrate **212** and first ILD layer **210** to the front volume **240** and inter-volume holes **246** extend through the MEMS substrate **236** between the front and back volumes **240**, **208**. In some embodiments, the protective layer **232** lines sidewalls of the environment port **244**. Further, a back plate isolation hole **248** extends through the MEMS substrate **236** to the second ILD layer **234** around the periphery of the front volume **240**. In some embodiments, the back plate isolation hole **248** further extends into the second ILD layer **234**. The back plate isolation hole **248** defines a back plate electrode **250** therebetween in the MEMS substrate **236** over the front volume **240**. The back plate electrode **250** is employed for MEMS device operations, and the back plate isolation hole **248** is employed to electrically isolate the back plate electrode **250**. The back plate electrode **250** typically corresponds to a highly doped region of the MEMS substrate **236**.

A conductive MEMS structure **252** of the MEMS device **202** is arranged in the second ILD layer **234** between the IC and MEMS substrates **212**, **236**, and extends laterally across the front volume **240**. In some embodiments, the conductive MEMS structure **252** is arranged over and abutting the ridges **242** of the etch stop layer **238**. The conductive MEMS structure **252** is connected to regions of the MEMS substrate **236** surrounding the back plate electrode **250** by a MEMS contact **254** of the MEMS device **202**. The MEMS contact **254** typically is or otherwise includes polysilicon. In some embodiments, the conductive MEMS structure **252** includes a membrane region **256** arranged within the front volume **240** and connected to peripheral, an anchor region **258** surrounding the membrane region **256**. Where the MEMS device **202** is a microphone, the membrane region **256** is spaced from and connected to the anchor region **258** by spring regions **260**. In operation, the membrane region **256** vibrates or otherwise deflects in accordance with sound received through the environment port **244**. Further, capacitive coupling between the back plate electrode **250** and the membrane region **256** is employed to measure the deflection. Where the MEMS device **202** is a pressure sensor, the membrane region **256** is directly connected to the anchor region **258** and bisects the front volume **240** into two independent sub-volumes. In operation, the membrane region **256** deflects in proportion to the difference between the environmental pressure and pressure in the back volume **208**. Further, capacitive coupling between the back plate electrode **250** and the membrane

region **256** is employed to measure the deflection. The conductive MEMS structure **252** typically is or otherwise includes polysilicon.

A stopper **262** of the MEMS device **202** is arranged in the front volume **240** over the top of the conductive MEMS structure **252** between the MEMS substrate **236** and the conductive MEMS structure **252**. The stopper **262** stops deflecting regions of the conductive MEMS structure **252**, such as the membrane region **256**, from sticking to the MEMS substrate **236** and from overextending in the vertical direction towards the MEMS substrate **236**. This advantageously reduces the likelihood of damage to the MEMS device **202** and increases the useful life of the MEMS device **202**. The stopper **262** is or otherwise includes, for example, polysilicon or a dielectric, such as silicon dioxide.

Second TSVs **264** of the MEMS device **202** extend through the MEMS substrate **236**, the second ILD layer **234**, and into the first ILD layer **210** to the interconnect components **216**, **218**. The second TSVs **264** include second conductive structures **266** arranged in corresponding second TSV holes **268**. The second conductive structures **266** typically line sidewalls of the second TSV holes **268** or fill the second TSV holes **268**. In some embodiments, second dielectric liners (not shown) line sidewalls of the second TSV holes **268** between the second conductive structures **266** and the sidewalls. The second dielectric liners typically are or otherwise include an oxide, such as silicon dioxide. The second conductive structures **266** typically are or otherwise include a metal, such as tungsten. The second TSVs **264** electrically couple the MEMS substrate **236**, including the back plate electrode **250**, and, in some embodiments, MEMS contact pads **270** to the interconnect components **216**, **218**. The MEMS contact pads **270** are arranged on the top of the MEMS substrate **236**, and improve the electrical interface between the second TSVs **264** and the MEMS substrate **236**. The MEMS contact pads **270** typically are or otherwise include metal, such as aluminum, copper, or aluminum copper.

TSV isolation holes **272** of the MEMS device **202** are arranged around the second TSVs **264** through the MEMS substrate **236** to the second ILD layer **234**. In some embodiments, the TSV isolation holes **272** extend into the second ILD layer **234**. The TSV isolation holes **272** electrically isolate the second TSVs **264** from neighboring regions of the MEMS substrate **236** with air gaps.

A MEMS bonding ring **274** of the MEMS device **202** is arranged on the MEMS substrate **236**, and a cap bonding ring **276** of the cap device **206** is arranged over the MEMS bonding ring **274** on a cap substrate **278** of the cap device **206**. The cap substrate **278** is a substrate over and/or within which the cap device **206** is arranged. The cap substrate **278** includes the back volume **208**, and is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. In other embodiments, the cap substrate **278** is a SOI or POI substrate. The MEMS and cap bonding rings **274**, **276** have like footprints and extend around the back volume **208**. The MEMS and cap bonding rings **274**, **276** bond the MEMS device **202** to the cap device **206** with a bond, typically a eutectic bond, at the interface between the MEMS and cap bonding rings **274**, **276**. Where the MEMS device **202** is a pressure sensor, in some embodiments, the bond hermetically seals the back volume **208** with a reference pressure employed for pressure measurements. The MEMS bonding ring **274** typically is or otherwise includes a metal, such as aluminum, copper, aluminum copper, copper tin, or gold, and the cap bonding ring **276** typically is or otherwise includes a metal, such as germanium, copper, or copper tin.

Advantageously, the MEMS packages of FIGS. **1** and **2** can be formed at the wafer level using TSVs. Wafer-level formation reduces parasitic capacitances between MEMS devices and the corresponding IC devices. Further, wafer-level formation reduces costs since the MEMS devices are packaged with the corresponding IC devices in bulk. In addition to the benefits that flow from wafer-layer formation, the MEMS package of FIG. **2** advantageously includes an etch stop layer to protect the IC device from damage during packaging.

With reference to FIG. **3**, a flowchart **300** provides some embodiments of a method for manufacturing a MEMS package including a MEMS device and an IC device connected by TSVs. The MEMS device is an environmental MEMS device, such as a microphone, pressure sensor, or other device interfacing with the external environment. Examples of the MEMS package are shown in FIGS. **1** and **2**.

A conductive MEMS structure is formed (Action **302**) in an ILD layer. The conductive MEMS structure includes a membrane region extending across an ILD region corresponding to a first volume. For a microphone, the membrane region is suspended within the first volume by spring regions of the conductive MEMS structure connecting the membrane region to an anchor region of the conductive MEMS structure around the periphery of the first volume.

A first bonding of a first wafer is performed (Action **304**) to a second wafer below the second wafer through the ILD layer, where a MEMS device includes the second wafer.

A TSV is formed (Action **306**) extending through the second wafer to electrically couple the MEMS device to an IC device corresponding to the MEMS device.

A second bonding of a third wafer is performed (Action **308**) to the second wafer over the second wafer to define a second volume between the second wafer and the third wafer. The IC device includes the first or third wafer.

With reference to FIGS. **4**A & B, flow charts **400**, **400'** of some embodiments of the method for manufacturing the MEMS package of FIG. **1**B is provided.

A first MEMS substrate is provided (Action **402**) with a first ring-shaped hole and with a second ring-shaped hole spaced from the first ring-shaped hole, the first and second ring-shaped holes surrounding via regions of the first MEMS substrate.

A first dielectric layer is formed (Action **404**) over the first MEMS substrate and lining the first and second ring-shaped holes.

Conductive cores are formed (Action **406**) between lined sidewalls of the first and second ring-shaped holes.

A conductive MEMS structure is formed (Action **408**) over the first dielectric layer, encapsulated by an ILD layer including the first dielectric layer, in electrical communication with the via regions by first contacts, and including a membrane region between the first and second ring-shaped holes.

Second contact holes and a stopper hole are formed (Action **410**) in the ILD layer, the second contacts over the via regions, and the stopper hole over the membrane region.

A second MEMS substrate is provided and bonded (Action **412**) to and over the first MEMS substrate through the ILD layer.

Second contacts in electrical communication with the conductive MEMS structure, a stopper over the membrane region, and first TSVs extending through the second MEMS substrate over the via regions and in electrical communication with the second contacts, are formed (Action **414**).

A MEMS bonding ring over the second MEMS substrate around the membrane region, and first MEMS contact pads outside the MEMS bonding ring, are formed (Action **416**).

Holes through the second MEMS substrate to isolate the second TSVs, to define a back plate electrode over the membrane region, and to expose sacrificial regions of the ILD layer surrounding the membrane region, are formed (Action **418**).

An IC device is provided and bonded (Action **420**) with the second MEMS substrate using the MEMS bonding ring to seal a back volume of the IC device over the back plate electrode and to electrically couple the IC device to the conductive MEMS structure through the MEMS contact pads, the second contacts and the first TSVs.

A planarization and/or etch back is performed (Action **422**) into a bottom of the first MEMS substrate and the first dielectric layer to the conductive cores to form second TSVs.

Second MEMS contact pads are formed (Action **424**) over a bottom of the first MEMS substrate, and in electrical communication with the second TSVs and the conductive MEMS structure through the second TSVs and the first contacts.

A second dielectric layer and a corresponding protective layer are formed (Action **426**) over a bottom of the first MEMS substrate, while leaving regions of the second MEMS contact pads exposed and an environment port region of the first MEMS substrate exposed.

An environment port is formed (Action **428**) through the first MEMS substrate in the environment port region.

The sacrificial regions are removed (Action **430**) to form a front volume surrounding the membrane region and below the back volume.

With reference to FIGS. **5**A & B, flow charts **500**, **500'** of some embodiments of the method for manufacturing the MEMS package of FIG. **2** is provided.

A MEMS substrate is provided (Action **502**) with a first dielectric layer arranged over a first side.

A contact hole and a stopper hole are formed (Action **504**) in the first dielectric layer. The contact hole is in communication with the MEMS substrate, and the stopper hole is over, but not in communication with, a back plate electrode region of the MEMS substrate.

A conductive layer is formed (Action **506**) over the first dielectric layer and filling the contact and stopper holes. Regions of the conductive layer filling the contact and stopper holes correspond to a contact and a stopper.

A conductive MEMS structure is formed (Action **508**) over the contact and stopper in the conductive layer. The conductive MEMS structure includes a membrane region over the stopper and an anchor region surrounding the membrane region.

A second dielectric layer is formed (Action **510**) over the conductive MEMS structure with an etch stop layer arranged therein. The etch stop layer includes ridges in communication with the anchor region of the conductive MEMS structure.

An IC device is provided and bonded (Action **512**) to the first side of the MEMS substrate through the first and second dielectric layers. The IC device includes an IC substrate over which interconnect components of the IC device connect electronic components of the IC device.

First TSVs are formed (Action **514**) extending through the MEMS substrate to the IC device.

On a second side of the MEMS substrate opposite the first side, a MEMS bonding ring extending around the membrane region and MEMS contact pads inside the MEMS bonding ring over the first TSVs are formed (Action **516**).

Holes are formed (Action **518**) through the MEMS substrate to isolate the first TSVs, to define a back plate electrode in the back plate electrode region, and to expose sacrificial regions of the first and second dielectric layers surrounding the membrane region.

A cap device is provided and bonded (Action **520**) with the MEMS substrate on the second side using the MEMS bonding ring to seal a back volume of the cap device over the back plate electrode.

Second TSVs through the IC substrate to the interconnect components, and IC contact pads next to or over the second TSVs, are formed (Action **522**).

An environment port is formed (Action **524**) below the membrane region, through the IC device, including the IC substrate, into the second dielectric layer, and through the etch stop layer.

A protective layer is formed (Action **526**) over a bottom of the IC substrate and lining sidewalls of the environment port, while leaving regions of the IC contact pads exposed and a top of the environment port exposed.

The sacrificial regions are removed (Action **528**) to form a front volume surrounding the membrane region and below the back volume.

Advantageously, the methods of FIGS. **3**, **4**A & B, and **5**A & B are performed at the wafer level using TSVs. Wafer-level formation of MEMS packages reduces parasitic capacitances between MEMS devices and the corresponding IC devices. Further, wafer-level formation reduces costs since the MEMS devices are packaged with the corresponding IC devices in bulk. In addition to the benefits that flow from wafer-layer formation, the methods of FIGS. **5**A & B employ an etch stop layer to protect the IC device from damage during packaging.

While the disclosed methods (e.g., the method described by the flowcharts **300**, **400**, **400'**, **500**, **500'**) are illustrated and described herein as a series of acts or events, it will be appreciated that the illustrated ordering of such acts or events are not to be interpreted in a limiting sense. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein. Further, not all illustrated acts may be required to implement one or more aspects or embodiments of the description herein, and one or more of the acts depicted herein may be carried out in one or more separate acts and/or phases.

With reference to FIGS. **6-19**, cross-sectional views of some embodiments of a MEMS package at various stages of manufacture are provided to illustrate the method of FIGS. **4**A & B. Although FIGS. **6-19** are described in relation to the method, it will be appreciated that the structures disclosed in FIGS. **6-19** are not limited to the method, but instead may stand alone as structures independent of the method. Similarly, although the method is described in relation to FIGS. **6-19**, it will be appreciated that the method is not limited to the structures disclosed in FIGS. **6-19**, but instead may stand alone independent of the structures disclosed in FIGS. **6-19**.

FIGS. **6** and **7** illustrate cross-sectional views **600**, **700** of some embodiments corresponding to Actions **402** and **404**.

As shown by FIG. **6**, a first MEMS substrate **108'** is provided. The first MEMS substrate **108'** is a substrate over and/or within which a MEMS device is formed. In some embodiments, the first MEMS substrate **108'** is a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. Alternatively, in other embodiments, the first MEMS substrate **108'** is a SOI or POI substrate.

As shown by FIG. **7**, a first etch is performed into select regions of the first MEMS substrate **108'** to define a first ring-shaped hole **702** and a second ring-shaped hole **704** spaced from the first ring-shaped hole **702**. The first and second ring-shaped holes **702**, **704** surround silicon via regions **706** of the remaining first MEMS substrate **108"**. The first etch includes, for example, one or more sub-etches, each

of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **7**, a first dielectric layer **708** is formed over the remaining first MEMS substrate **108"**. Further, the first dielectric layer **708** is formed lining the first and second ring-shaped holes **702**, **704**, while leaving gaps **710** between the lined sidewalls of the first and second ring-shaped holes **702**, **704**. The first dielectric layer **708** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the first dielectric layer **708** is conformally formed and/or formed of an oxide, such as silicon dioxide.

FIGS. **7** and **8** illustrate cross-sectional views **700**, **800** of some embodiments corresponding to Action **406**.

As shown by FIG. **7**, a first conductive layer **712** is formed over the first dielectric layer **708** and filling the gaps **710** between the lined sidewalls of the first and second ring-shaped holes **702**, **704**. The first conductive layer **712** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the first conductive layer **712** is formed of polysilicon.

As shown by FIG. **8**, a first planarization and/or etch back is performed into the first conductive layer **712** to the first dielectric layer **708**. The first planarization and/or etch back forms conductive cores **158** between the lined sidewalls of the first and second ring-shaped holes **702**, **704**. In some embodiments, the first planarization and/or etch back includes a chemical-mechanical planarization (CMP).

FIGS. **8-11** illustrate cross-sectional views **800**, **900**, **1000**, **1100** of some embodiments corresponding to Action **408**.

As shown by FIG. **8**, a second dielectric layer **802** is formed over the first dielectric layer **708** and the conductive cores **158**. The second dielectric layer **802** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the second dielectric layer **802** is formed of an oxide, such as silicon dioxide.

As shown by FIG. **9**, a second etch is performed through select regions of the first and second dielectric layers **708**, **802**. The second etch forms first contact holes **902** over the silicon via regions **706**. The second etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **9**, a second conductive layer **904** is formed over the remaining second dielectric layer **802'** and filling the first contact holes **902**. Regions of the second conductive layer **904** filling the first contact holes **902** correspond to first MEMS contacts **160**. The second conductive layer **904** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the second conductive layer **904** is polysilicon.

As shown by FIG. **10**, a third etch is performed into select regions of the second conductive layer **904**. The third etch forms a conductive MEMS structure **104** arranged over and in electrical communication with the first MEMS contacts **160**. The conductive MEMS structure **104** is tailored to a predetermined type of MEMS device, such as, for example, a microphone, pressure sensor, or any other type of MEMS device requiring environmental exposure. For a microphone, the conductive MEMS structure **104** includes an anchor region **122** arranged around and spaced from a membrane region **120**, and connected to the membrane region **120** by spring regions **146**. For a pressure sensor, the conductive MEMS structure **104** includes the anchor region **122** directly connected to the membrane region **120**. The third etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **10**, a third dielectric layer **1002** is formed over the remaining second dielectric layer **802'** and the conductive MEMS structure **104**. The remaining first and second dielectric layers **708'**, **802'** and the third dielectric layers **1002** collectively define a first ILD layer **106'** encapsulating the conductive MEMS structure **104**. The third dielectric layer **1002** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the third dielectric layer **1002** is formed of an oxide, such as silicon dioxide.

As shown by FIG. **11**, a second planarization and/or etch back is performed into the first ILD layer **106'**, including the third dielectric layer **1002**. In some embodiments, the second planarization and/or etch back includes a CMP.

FIG. **11** illustrates a cross-sectional view **1100** of some embodiments corresponding to Actions **410** and **412**.

As shown by FIG. **11**, a fourth etch is performed into select regions of the third dielectric and first ILD layers **1002**, **106'** to form second contact holes **1102** in communication with the conductive MEMS structure **104**. Typically, the second contact holes **1102** are in communication with the anchor region **122** of the conductive MEMS structure **104**, and/or arranged over the silicon via regions **706**. The fourth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **11**, a fifth etch is performed into select regions of the third dielectric and first ILD layers **1002**, **106'** to form a stopper hole **1104** over the membrane region **120**, but not in communication with the membrane region **120**. Typically, the stopper hole **1104** is arranged over the center of the membrane region **120**. The fifth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **11**, a second MEMS substrate **112'** is provided. Like remaining first MEMS substrate **108"**, the second MEMS substrate **112'** is a substrate over and/or within which a MEMS device is formed. In some embodiments, the second MEMS substrate **112'** is a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. Alternatively, the second MEMS substrate **112'** is, for example, a SOI or POI substrate.

Also shown by FIG. **11**, the second MEMS substrate **112'** is bonded to the remaining first MEMS substrate **108"** through the remaining first ILD layer **106"**, including the remaining third dielectric layer **1002'**. The second MEMS substrate **112'** is typically bonded to the remaining first MEMS substrate **108"** by a fusion bond at the interface between the second MEMS substrate **112'** and the remaining third dielectric layer **1002'**.

FIGS. **12** and **13** illustrate cross-sectional views **1200**, **1300** of some embodiments corresponding to Action **414**.

As shown by FIG. **12**, third planarization and/or etch back is performed into the second MEMS substrate **112'** to thin down the second MEMS substrate **112'** to the desired thickness. In some embodiments, the third planarization and/or etch back includes a CMP.

Also shown by FIG. **12**, a sixth etch is performed through select regions of the second MEMS substrate **112'** to define

second TSV holes **168** over the stopper hole **1104** and over the second contact holes **1102**. The sixth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **12**, a third conductive layer **1202** is formed over the remaining second MEMS substrate **112"**, and filling the second TSV holes **168**, the stopper hole **1104**, and the second contact holes **1102**. Regions of the third conductive layer **1202** filling the second contact holes **1102** correspond to second MEMS contacts **172**, and regions of the third conductive layer **1202** filling the stopper hole **1104** correspond to a stopper **148**. The third conductive layer **1202** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the third conductive layer **1202** is polysilicon.

As shown by FIG. **13**, a fourth planarization and/or etch back is performed into the third conductive layer **1202** to the remaining second MEMS substrate **112"** to form second TSVs **128**. In some embodiments, the fourth planarization and/or etch back includes a CMP.

FIGS. **13** and **14** illustrate cross-sectional views **1300**, **1400** of some embodiments corresponding to Action **416**.

As shown by FIG. **13**, a fourth conductive layer **1302** is formed over the remaining second MEMS substrate **112"** and the second TSVs **128**. The fourth conductive layer **1302** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the fourth conductive layer **1302** is a metal, such as aluminum, copper, aluminum copper, copper tin, or gold.

As shown by FIG. **14**, a seventh etch is performed through select regions of the fourth conductive layer **1302**. The seventh etch defines a MEMS bonding ring **176** arranged around the membrane region **120**. Further, the seventh etch defines first MEMS contacts pads **170** arranged over the second TSVs **128** outside the MEMS bonding ring **176**. The seventh etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIG. **14** illustrates a cross-sectional view **1400** of some embodiments corresponding to Action **418**.

As shown by FIG. **14**, an eighth etch is performed through select regions of the remaining second MEMS substrate **112"**. The eighth etch forms TSV isolation holes **174** around the second TSVs **128**, and a back plate isolation hole **144** along the inner sidewall of the MEMS bonding ring **176**. Regions of the second MEMS substrate **112"** surrounded by the back plate isolation hole **144** correspond to a back plate electrode **114**. Further, the eighth etch forms inter-volume holes **124** through the back plate electrode **114** to expose sacrificial regions of the remaining first ILD layer **106"**, including the remaining first, second and third dielectric layers **708'**, **802'**, **1002'**, surrounding the membrane region **120**. The eighth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIG. **14** illustrates a cross-sectional view **1400** of some embodiments corresponding to Action **420**.

As shown by FIG. **14**, an IC device **126'** is provided. The IC device **126'** includes an IC substrate **116** having a back volume **118**. The IC substrate **116** is a substrate over and/or within which the IC device **126'** is formed. Further, the IC substrate **116** is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. Alternatively, the IC substrate **116** is, for example, a SOI or POI substrate. An electronic components layer **136** is arranged around the back volume **118** over and/or within a bottom of the IC substrate **116**, and a second ILD layer **134'** is arranged around the back volume **118** over the electronic components layer **136**. Electronic components of the electronic components layer **136** are electrically connected with each other and IC contact pads **180** by interconnect components **182**, **184** arranged within the second ILD layer **134'**. The IC contact pads **180** are arranged over a bottom of the second ILD layer **134'** with an IC bonding ring **178** extending around the back volume **118** between the IC contact pads **180** and the back volume **118**. The second ILD layer **134'** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the second ILD layer **134'** is formed of an oxide, such as silicon dioxide.

Also shown by FIG. **14**, the IC device **126'** is bonded to the remaining second MEMS substrate **112** with the back volume **118** over the back plate electrode **114** to seal the back volume **118** over the back plate electrode **114**. The IC device **126'** is typically bonded to the remaining second MEMS substrate **112** by a eutectic bond at the interface between the MEMS and IC bonding rings **176**, **178**. Further, the IC contact pads **180** electrically couple with corresponding first MEMS contact pads **170**, typically with a eutectic bond at the interface.

FIG. **15** illustrates a cross-sectional view **1500** of some embodiments corresponding to Action **422**.

As shown by FIG. **15**, a fifth planarization and/or etch back is performed into the remaining first MEMS substrate **108"** and the remaining first dielectric layer **708'** to expose the conductive cores **158** and to form first TSVs **138**. In some embodiments, the fifth planarization and/or etch back includes a CMP.

FIGS. **15** and **16** illustrate cross-sectional views **1500**, **1600** of some embodiments corresponding to Action **424**.

As shown by FIG. **15**, a fifth conductive layer **1502** is formed over a bottom of the remaining first MEMS substrate **108"**, the remaining first dielectric layer **708'**, and the first TSVs **138**. The fifth conductive layer **1502** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the fifth conductive layer **1502** is a metal, such as aluminum, copper, or aluminum copper.

As shown by FIG. **16**, a ninth etch is performed through select regions of the fifth conductive layer **1502** to form second MEMS contact pads **140** over the first TSVs **138**. The second MEMS contact pads **140** are in electrical communication with the first TSVs **138** and the conductive MEMS structure **104**. The ninth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIGS. **16-18** illustrate cross-sectional views **1600**, **1700**, **1800** of some embodiments corresponding to Action **426**.

As shown by FIG. **16**, a fourth dielectric layer **162'** is formed over the remaining first MEMS substrate **108"'** and the second MEMS contact pads **140**. The fourth dielectric layer **162'** is typically formed conformally, and is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the fourth dielectric layer **162'** is formed of an oxide, such as silicon dioxide.

As shown by FIG. **17**, a tenth etch is performed through select regions of the fourth dielectric layer **162'** to expose the second MEMS contact pads **140** and to expose an environ-

ment port region **1702** of the remaining first MEMS substrate **108"** below the membrane region **120**. Typically, there is a margin or space between the environment port region **1702** and the remaining fourth dielectric layer **162**. The tenth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **17**, a protective layer **164'** is formed over the remaining fourth dielectric layer **162**, the environment port region **1702**, and the second MEMS contact pads **140**. As seen hereafter, the protective layer **164'** protects the remaining fourth dielectric layer **162** from vapor hydrofluoric acid. The protective layer **164'** is typically formed conformally, and is or otherwise includes, for example, a material resistive to vapor hydrofluoric acid, such as low stress nitride, aluminum nitride, aluminum oxide, or silicon carbide.

As shown by FIG. **18**, an eleventh etch is performed through select regions of the protective layer **164'**. The eleventh etch exposes the second MEMS contact pads **140** and the environment port region **1702**, while lining or otherwise covering all surfaces of the remaining fourth dielectric layer **162**. The eleventh etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIG. **18** illustrates a cross-sectional view **1800** of some embodiments corresponding to Action **428**.

As shown by FIG. **18**, a twelfth etch is performed through select regions of the protective layer **164'** and through the environment port region **1702** to form an environment port **110**. In some embodiments, the twelfth etch extends into and/or through the remaining first ILD layer **106"**, including the remaining first and/or second dielectric layers **708"**, **802'**. The twelfth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIG. **19** illustrates a cross-sectional view **1900** of some embodiments corresponding to Action **430**.

As shown by FIG. **19**, a thirteenth etch is performed into the remaining first ILD layer **106'"**, including the remaining first, second and third dielectric layers **708'"**, **802'**, **1002'**, and the second ILD layer **134'** to form a front volume **142** between the remaining first and second MEMS substrates **108**, **112** below the back plate electrode **114**. In some embodiments, the process for the twelfth etch includes introducing vapor hydrofluoric acid to the remaining first ILD layer **106'"** and the second ILD layer **134'** through the environment port **110**. In other embodiments, the vapor hydrofluoric acid is also introduced through a hole (not shown) in the IC substrate **116'** leading to the back volume **118**. This hole is subsequently sealed by forming a sealing layer (not shown) thereover. The thirteenth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

With reference to FIGS. **20-32**, cross-sectional views of some embodiments of a MEMS package at various stages of manufacture are provided to illustrate the method of FIGS. **5**A & B. Although FIGS. **20-32** are described in relation to the method, it will be appreciated that the structures disclosed in FIGS. **20-32** are not limited to the method, but instead may stand alone as structures independent of the method. Similarly, although the method is described in relation to FIGS. **20-32**, it will be appreciated that the method is not limited to the structures disclosed in FIGS. **20-32**, but instead may stand alone independent of the structures disclosed in FIGS. **20-32**.

FIG. **20** illustrates a cross-sectional view **2000** of some embodiments corresponding to Action **502**.

As shown by FIG. **20**, a MEMS substrate **236'** is provided. The MEMS substrate **236'** is a substrate over and/or within which a MEMS device is formed. The MEMS substrate **236'** is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. Alternatively, the MEMS substrate **236'** is, for example, a SOI or POI substrate.

Also shown by FIG. **20**, a first dielectric layer **2002** is formed over the MEMS substrate **236'**. The first dielectric layer **2002** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the first dielectric layer **2002** is formed of an oxide, such as silicon dioxide.

FIG. **21** illustrates a cross-sectional view **2100** of some embodiments corresponding to Actions **504** and **506**.

As shown by FIG. **21**, a first etch is performed through select regions of the first dielectric layer **2002** to define a stopper hole **2102** over, but not in communication with, a back plate electrode region **2104** (shown in dashed lines) of the MEMS substrate **236'**. The first etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **21**, a second etch is performed through select regions of the first dielectric layer **2002** to define a first contact hole **2106** in communication with regions of the MEMS substrate **236'** surrounding the back plate electrode region **2104**. The second etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **21**, a first conductive layer **2108** is formed over the remaining first dielectric layer **2002'** and filling the first contact and stopper holes **2106**, **2102**. Regions of the first conductive layer **2108** filling the first contact and stopper holes **2106**, **2102** correspond to a MEMS contact **254** and a stopper **262**. The first conductive layer **2108** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the first conductive layer **2108** is formed of polysilicon.

FIG. **22** illustrates a cross-sectional view **2200** of some embodiments corresponding to Action **508**.

As shown by FIG. **22**, a third etch is performed through select regions of the first conductive layer **2108**. The third etch forms a conductive MEMS structure **252** arranged over and in electrical communication with the MEMS contact **254** and the stopper **262**. The conductive MEMS structure **252** is tailored to a predetermined type of MEMS device, such as, for example, a microphone, pressure sensor, or any other type of MEMS device requiring environmental exposure. For a microphone, the conductive MEMS structure **252** includes an anchor region **258** arranged around and spaced from a membrane region **256**, and connected to the membrane region **256** by spring regions **260**. For a pressure sensor, the conductive MEMS structure **252** includes the anchor region **258** directly connected to the membrane region **256**. The third etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and

isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIGS. **22-24** illustrate cross-sectional views **2200**, **2300**, **2400** of some embodiments corresponding to Action **510**.

As shown by FIG. **22**, a second dielectric layer **2202** is formed over the remaining first dielectric layer **2002'** and the conductive MEMS structure **252**. The second dielectric layer **2202** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the second dielectric layer **2202** is formed of an oxide, such as silicon dioxide.

As shown by FIG. **23**, a first planarization and/or etch back is performed into the second dielectric layer **2202**. In some embodiments, the first planarization and/or etch back includes a CMP.

Also shown by FIG. **23**, fourth etch is performed into the second dielectric layer **2202** to define anchor holes **2302** in communication with the anchor region **258**. The fourth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **23**, an etch stop layer **238'** is formed over the remaining second dielectric layer **2202'** and lining the anchor holes **2302**. Regions of the etch stop layer **238'** lining the anchor holes **2302** define ridges **242**. The ridges **242** are inverted and provide a lateral etch stop for region of the remaining second dielectric layer **2202'** surrounding the anchor region **258**. The etch stop layer **238'** is typically formed conformally, and is or otherwise includes, for example, a material resistive to vapor hydrofluoric acid, such as low stress nitride, aluminum nitride, aluminum oxide, or silicon carbide.

Also shown by FIG. **23**, a third dielectric layer **2304** is formed over the etch stop layer **238'** and filling any gaps between the lined sidewalls of the anchor holes **2302**. The remaining first and second dielectric layers **2002'**, **2202'** and the third dielectric layer **2304** collectively form a first ILD layer **234'**. The third dielectric layer **2304** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the third dielectric layer **2304** is formed of an oxide, such as silicon dioxide.

As shown by FIG. **24**, a second planarization and/or etch back is performed into the third dielectric layer **2304** and the first ILD layer **234'**. In some embodiments, the second planarization and/or etch back includes a CMP.

FIG. **24** illustrates a cross-sectional view **2400** of some embodiments corresponding to Action **512**.

As shown by FIG. **24**, an IC device **204'** is provided. The IC device **204'** includes an IC substrate **212'** over which interconnect components **216**, **218** of the IC device **204'** connect electronic components of an electronic components layer **214'** of the IC device **204'**. The IC substrate **212'** is a substrate over and/or within which the IC device **204'** is formed. Further, the IC substrate **212'** is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. Alternatively, the IC substrate **212'** is, for example, a SOI or POI substrate. The electronic components layer **214'** is arranged over and/or within the IC substrate **212'**, and a second ILD layer **210'** is over the electronic components layer **214'** around the interconnect components **216**, **218**. The second ILD layer **210'** is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the second ILD layer **210'** is formed of an oxide, such as silicon dioxide.

Also shown by FIG. **24**, the IC device **204'** is bonded to the MEMS substrate **236'** through the remaining first ILD layer **234"**, including the remaining third dielectric layer **2304'**. The IC device **204'** is typically bonded to the MEMS substrate **236'** by a fusion bond at the interface between the remaining first ILD layer **234"** and the second ILD layer **210'**.

FIGS. **25** and **26** illustrate cross-sectional views **2500**, **2600** of some embodiments corresponding to Action **514**.

As shown by FIG. **25**, a third planarization and/or etch back is performed into the MEMS substrate **236'** to thin down the MEMS substrate **236'** to the desired thickness. In some embodiments, the third planarization and/or etch back includes a CMP.

Also shown by FIG. **25**, a fifth etch is performed is performed through and/or into select regions of the MEMS substrate **236'**, the remaining first ILD layer **234"**, the etch stop layer **238'**, and the second ILD layer **210'** to the interconnect components **216**, **218** of the IC device **204'**. The fifth etch results in second TSV holes **268**. The fifth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **25**, a second conductive layer **2502** is formed over the remaining MEMS substrate **236"** and filling the second TSV holes **268**. The second conductive layer **2502** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the second conductive layer **2502** is formed of a metal, such as tungsten.

As shown by FIG. **26**, a fourth planarization and/or etch back is performed into the second conductive layer **2502** to form second TSVs **264** extending through the remaining MEMS substrate **236"**, the remaining first ILD layer **234"**, including the remaining first, second and third dielectric layers **2002"**, **2202"**, **2304"**, the remaining etch stop layer **238"**, and the remaining second ILD layer **210"**. In some embodiments, the fourth planarization and/or etch back includes a CMP.

FIGS. **26** and **27** illustrate cross-sectional views **2600**, **2700** of some embodiments corresponding to Action **516**.

As shown by FIG. **26**, a third conductive layer **2602** is formed over the remaining MEMS substrate **236"** and the second TSVs **264**. The third conductive layer **2602** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the third conductive layer **2602** is a metal, such as aluminum, copper, or aluminum copper.

As shown by FIG. **27**, a sixth etch is performed through select regions of the third conductive layer **2602**. The sixth etch defines a MEMS bonding ring **274** arranged around the membrane region **256**. Further, the sixth etch defines MEMS contacts pads **270** arranged over the second TSVs **264** inside the MEMS bonding ring **274**. The sixth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIG. **27** illustrates a cross-sectional view **2700** of some embodiments corresponding to Actions **518** and **520**.

As shown by FIG. **27**, a seventh etch is performed through select regions of the remaining MEMS substrate **236"**. The seventh etch forms TSV isolation holes **272** around the second TSVs **264**, and a back plate isolation hole **248** around the back plate electrode region **2104** of the remaining MEMS substrate **236**. Regions of the remaining MEMS substrate **236"** surrounded by the back plate isolation hole **248** correspond to a back plate electrode **250**. Further, the seventh etch forms inter-volume holes **246** through the back plate elec-

trode region **2104** to expose sacrificial regions of the remaining first ILD layer **234'**, including the remaining first, second and third dielectric layers **2002"**, **2202"**, **2304"** surrounding the membrane region **256**. The seventh etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **27**, a cap device **206** is provided. The cap device **206** includes a cap substrate **278** having a back volume **208**. The cap substrate **278** is a substrate over and/or within which the cap device **206** is formed. Further, the cap substrate **278** is typically a bulk semiconductor substrate including, for example, one or more of silicon, germanium, silicon carbide, a group III element, and a group V element. Alternatively, the cap substrate **278** is, for example, a SOI or POI substrate. The cap device **206** further includes a cap bonding ring **276** extending around the back volume **208**.

Also shown by FIG. **27**, the cap device **206** is bonded to the remaining MEMS substrate **236** with the back volume **208** over the back plate electrode **250** to seal the back volume **208** over the back plate electrode **250**. The cap device **206** is typically bonded to the remaining MEMS substrate **236** by a eutectic bond at the interface between MEMS and cap bonding rings **274**, **276**.

FIG. **28-30** illustrates a cross-sectional view **2800**, **2900**, **3000** of some embodiments corresponding to Action **522**.

As shown by FIG. **28**, a fifth planarization and/or etch back is performed into the IC substrate **212'** to thin down the IC substrate **212'** to the desired thickness. In some embodiments, the fifth planarization and/or etch back includes a CMP.

Also shown by FIG. **28**, an eighth etch is performed through and/or into select regions of the IC substrate **212'**, the electronic components layer **214'**, and the remaining second ILD layer **210"** to the interconnect components **216**, **218**. The eighth etch result in first TSV holes **224**. The eighth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **28**, a fourth dielectric layer **2802** is formed over the remaining IC substrate **212"** and lining the first TSV holes **224**. The fourth dielectric layer **2802** is typically formed conformally, and is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the fourth dielectric layer **2802** is formed of an oxide, such as silicon dioxide.

As shown by FIG. **29**, an ninth etch is performed through select regions of the fourth dielectric layer **2802** to expose the interconnects component **216**, **218**. The ninth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Also shown by FIG. **29**, a fourth conductive layer **2902** is formed over the remaining fourth dielectric layer **2802'** and the exposed interconnect components **216**, **218**. The fourth conductive layer **2902** is or otherwise includes a conductor, such as polysilicon or a metal. Typically, the fourth conductive layer **2902** is formed conformally, and/or is a metal, such as aluminum, copper, or aluminum copper.

As shown by FIG. **30**, a tenth etch is performed through select regions of the fourth conductive layer **2902** to form first TSVs **220** extending through the remaining IC substrate **212"**, the remaining electronic components layer **214"**, and the remaining second ILD layer **210"'** to the interconnect components **216**, **218**. The tenth etch also forms IC contact pads **228** arranged next to the first TSVs **220** in electrical communication with the first TSVs **220**. The tenth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIG. **30** illustrates a cross-sectional view **3000** of some embodiments corresponding to Action **524**.

As shown by FIG. **30**, an eleventh etch is performed through select regions of the remaining fourth dielectric layer **2802'**, the remaining IC substrate **212"**, the remaining second ILD layer **210"'**, and the remaining etch stop layer **238"** to form an environment port **244** below the membrane region **256**. The eleventh etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIGS. **30** and **31** illustrate cross-sectional views **3000**, **3100** of some embodiments corresponding to Action **526**.

As shown by FIG. **30**, a protective layer **232'** is formed over the remaining IC substrate **212**, the IC contact pads **228**, and the first TSVs **220**. The protective layer **232'** is also formed lining the environment port **244** and any free space in the first TSV holes **224**. As seen hereafter, the protective layer **232'** protects the remaining fourth dielectric layer **2802"** from vapor hydrofluoric acid. The protective layer **232'** is typically formed conformally, and is or otherwise includes, for example, a material resistive to vapor hydrofluoric acid, such as low stress nitride, aluminum nitride, aluminum oxide, or silicon carbide.

Also shown by FIG. **30**, a fifth dielectric layer **3002** is formed over the protective layer **232'**. The fifth dielectric layer **3002** is typically formed conformally, and is or otherwise includes a dielectric, such as, for example, silicon dioxide, silicon oxynitride, or silicon nitride. Typically, the fifth dielectric layer **3002** is formed of an oxide, such as silicon dioxide.

As shown by FIG. **31**, a twelfth etch is performed through the protective layer **232'** and the fifth dielectric layer **3002** to expose a top surface of the environment port **244** and to expose the IC contact pads **228**. The twelfth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

FIG. **32** illustrate cross-sectional views **3200** of some embodiments corresponding to Action **528**.

As shown by FIG. **32**, a thirteenth etch is performed into the remaining first ILD layer **234"**, including the remaining first and second dielectric layers **2002"**, **2202"**, and through the remaining fifth dielectric layer **3002**. During the thirteenth etch, the remaining protective layer **232** and the remaining etch stop layer **238** protect the remaining second ILD layer **210** and the remaining third dielectric layer **2304"'**. In some embodiments, the process for the thirteenth etch includes introducing vapor hydrofluoric acid to the remaining first ILD layer **234"'** through the environment port **244**. In other embodiments, the vapor hydrofluoric acid is also introduced through a hole (not shown) in the cap substrate **278** leading to the back volume **208**. This hole is subsequently sealed by forming a sealing layer (not shown) thereover. The thirteenth etch includes, for example, one or more sub-etches, each of which is anisotropic, isotropic, or a combination of anisotropic and isotropic, and each of which is a wet etch, a dry etch (e.g., a plasma etch), or a combination of wet and dry etches

Thus, as can be appreciated from above, the present disclosure provides a MEMS package. A conductive MEMS structure is arranged in an ILD layer and includes a membrane region extending across a first volume arranged in the ILD layer. A first substrate is bonded to a second substrate through the ILD layer. A MEMS device includes the second substrate. A TSV extends through the second substrate to electrically couple the MEMS device to an IC device. A third substrate is bonded to the second substrate to define a second volume between the second substrate and the third substrate. The IC device includes the first or third substrate.

In other embodiments, the present disclosure provides a method for manufacturing a MEMS package. A conductive MEMS structure is formed in an ILD layer. The conductive MEMS structure includes a membrane region extending across an ILD region corresponding to a first volume. A first bonding of a first wafer to a second wafer is performed through the ILD layer. A MEMS device includes the second wafer. A TSV is formed extending through the second wafer to electrically couple the MEMS device to an IC device. A second bonding of a third wafer to the second wafer is performed over the second wafer to define a second volume between the second wafer and the third wafer. The IC device includes the first or third wafer.

In yet other embodiments, the present disclosure provides a MEMS package. A MEMS device includes a MEMS substrate. An IC device includes an IC substrate bonded to the MEMS substrate over or below the MEMS substrate. The IC device is further electrically coupled to the MEMS device with a TSV extending through the MEMS substrate. A conductive membrane is arranged below the MEMS substrate between the MEMS substrate and a first substrate, and is arranged across a first volume arranged between the MEMS substrate and the first substrate. A second volume is arranged over the MEMS device between the MEMS substrate and a second substrate. The IC substrate is one of the first substrate and the second substrate. An environment port extends through the first substrate to the first volume and is configured to expose the conductive membrane to an external environment of the MEMS package.

The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A microelectromechanical systems (MEMS) package comprising:

a conductive MEMS structure arranged in a dielectric layer and including a membrane region extending across a first volume arranged in the dielectric layer;

a first substrate bonded to a second substrate through the dielectric layer, wherein a MEMS device includes the second substrate;

a through silicon via (TSV) extending through the second substrate to electrically couple the MEMS device to an IC device; and

a third substrate bonded to the second substrate to define a second volume between the second substrate and the third substrate, wherein the IC device includes the first or third substrate.

2. The MEMS package according to claim **1**, wherein the MEMS device is a microphone.

3. The MEMS package according to claim **1**, further including:

an environment port extending through the first substrate to the first volume and configured to expose the membrane region to an external environment of the MEMS package.

4. The MEMS package according to claim **1**, wherein the IC device includes the third substrate.

5. The MEMS package according to claim **1**, wherein the IC device includes the first substrate, and wherein the MEMS package further includes:

a cap device including the third substrate.

6. The MEMS package according to claim **1**, further including:

a back plate electrode arranged in the second substrate over the membrane region and capacitively coupled with the membrane region.

7. The MEMS package according to claim **1**, further including:

a second dielectric layer arranged between the first substrate and the second substrate below the dielectric layer; and

an etch stop layer arranged in the dielectric layer, and configured to define surfaces of the first volume and to protect a fusion bond interface between the dielectric layer and the second dielectric layer.

8. The MEMS package according to claim **7**, wherein the etch stop layer is configured to protect the dielectric layer from vapor hydrofluoric acid.

9. The MEMS package according to claim **1**, wherein the conductive MEMS structure includes an anchor region around a periphery of the first volume and connected to the membrane region by spring regions, and wherein the anchor region protrudes laterally into the first volume from within the dielectric layer.

10. A microelectromechanical systems (MEMS) package comprising:

a MEMS device having a MEMS substrate;

an integrated circuit (IC) device having an IC substrate bonded to the MEMS substrate over or below the MEMS substrate, and electrically coupled to the MEMS device with a through substrate via (TSV) extending through the MEMS substrate;

a conductive membrane arranged below the MEMS substrate between the MEMS substrate and a first substrate, and arranged across a first volume arranged between the MEMS substrate and the first substrate;

a second volume arranged over the MEMS device between the MEMS substrate and a second substrate, wherein the IC substrate is one of the first substrate and the second substrate; and

an environment port extending through the first substrate to the first volume and configured to expose the conductive membrane to an external environment of the MEMS package.

11. The MEMS package according to claim **10**, wherein the MEMS device is a microphone.

12. The MEMS package according to claim **10**, further comprising:

a first dielectric layer arranged between the first substrate and the MEMS substrate; and

a first etch stop layer arranged in the first dielectric layer and configured to define surfaces of the first volume, wherein the environment port extends through the first etch stop layer.

13. The MEMS package according to claim **12**, further comprising:

a second dielectric layer arranged between the first dielectric layer and the first substrate, and interfacing with the first dielectric layer at a fusion bond; and

a second etch stop layer lining the environment port, and configured to protect the second dielectric layer from an etchant.

14. The MEMS package according to claim **10**, further comprising:

a silicon via extending through the first substrate to a bond pad on a lower surface of the first substrate;

a dielectric layer arranged on the lower surface of the first substrate; and

an etch stop layer confined to below the lower surface of the first substrate, lining the dielectric layer, and configured to protect the dielectric layer from an etchant.

15. The MEMS package according to claim **10**, wherein the IC substrate is the first substrate, and wherein the MEMS package further includes:

a cap device including the second substrate.

16. A microelectromechanical systems (MEMS) package comprising:

a MEMS device comprising a dielectric layer laterally surrounding a first volume, and further comprising a conductive membrane and a MEMS substrate, the conductive membrane arranged in the first volume, and the MEMS substrate arranged over and interfacing with the dielectric layer;

an integrated circuit (IC) device bonded to the MEMS device, and electrically coupled to the MEMS device with a through substrate via (TSV) extending through the MEMS substrate;

an environment port arranged on a lower side of the first volume and configured to expose the conductive membrane to an external environment of the MEMS package; and

a second volume arranged over the MEMS substrate in fluid communication with the first volume through the MEMS substrate.

17. The MEMS package according to claim **16**, wherein the IC device is arranged over the MEMS substrate, and comprises an IC substrate and an interlayer dielectric (ILD) layer, wherein the IC substrate is bonded to the MEMS substrate through the ILD layer, and wherein the second volume is arranged between the IC substrate and the MEMS substrate.

18. The MEMS package according to claim **16**, wherein the IC device is arranged below the dielectric layer, and comprises an IC substrate and an interlayer dielectric (ILD) layer, wherein the IC substrate is bonded to the MEMS substrate through a fusion bond interface between the ILD layer and the dielectric layer, and wherein the environment port extends through the IC device.

19. The MEMS package according to claim **18**, further comprising:

an etch stop layer arranged in the dielectric layer, and configured to define surfaces of the first volume and to protect the fusion bond interface from an etchant.

20. The MEMS package according to claim **18**, further comprising:

a cap substrate arranged over and bonded to the MEMS substrate, wherein the second volume is arranged between the cap substrate and the MEMS substrate.

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